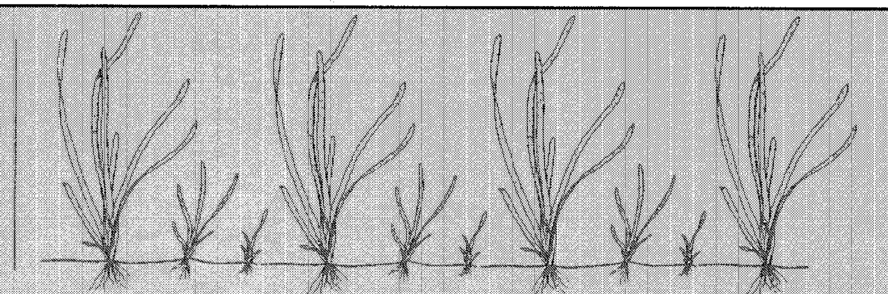
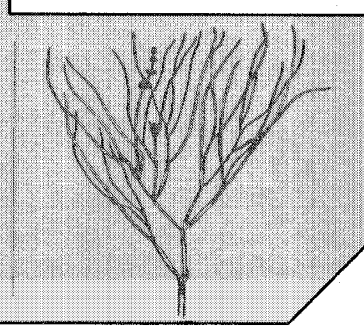
Richard V. Batiuk



Submerged Aquatic Vegetation Habitat Requirements and Restoration Targets: A Technical Synthesis

Chesapeake Bay



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Chesapeake Bay Submerged Aquatic Vegetation Habitat Requirements and Restoration Targets: A Technical Synthesis

Annapolis, Maryland
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Executive Summary

Worldwide, estuaries are experiencing water quality problems as a result of the pressures from increasing numbers of people moving to coastal areas. Chesapeake Bay, one of the world's largest estuaries, has experienced deterioration of water quality from nutrient enrichment, resulting in anoxic or hypoxic conditions and declines in living resources. Determination of relationships between water quality and various living resources provides a mechanism of relating anthropogenic inputs to the "health" of Chesapeake Bay. In particular, the establishment of habitat requirements and restoration targets for critical species living in Chesapeake Bay is a way in which scientists, resource managers, politicians, and the public can work toward the goal of restoring the Chesapeake Bay.

One of the major factors contributing to the high productivity of Chesapeake Bay has been the historical abundance of submerged aquatic vegetation (SAV). SAV in Chesapeake Bay include some twenty freshwater and marine species of rooted, flowering plants. SAV provide food for waterfowl and are critical habitat for shellfish and finfish. SAV also affect nutrient cycling, sediment stability, and water turbidity. However, a baywide decline of all SAV species in Chesapeake Bay began in the late 1960s and early 1970s. This SAV decline was related to increasing amounts of nutrients and sediments in the Bay, resulting from development of the Bay's shoreline and surrounding watershed.

The Chesapeake Executive Council's adoption of a Chesapeake Bay Submerged Aquatic Vegetation Policy and an Implementation Plan for the SAV Policy highlighted not only the need to develop SAV habitat requirements but also the need for baywide restoration goals for SAV distribution, density, and species diversity. In response to the commitments described in the SAV Policy Implementation Plan, a working group of scientists and managers produced the "Chesapeake Bay Submerged Aquatic Vegetation Habitat Requirements and Restoration Targets: A Technical Synthesis."

The primary objective of the SAV Technical Synthesis is to establish the quantitative levels of relevant water quality parameters necessary to support continued survival, propagation, and restoration of SAV. Secondary objectives are to: establish regional SAV distribution, density, and species diversity targets for the Chesapeake Bay and its tributaries; document the baywide applicability of habitat requirements developed through the case studies in the synthesis; and assess the applicability of mid-channel monitoring data for evaluating the water quality in adjacent shallow water habitats.

A conceptual model of the interactions and interdependence of the SAV habitat requirements (Figure 1) illustrates the water quality parameters that influence SAV distribution and abundance. A wealth of scien-

Conceptual Model of SAV Habitat Interactions

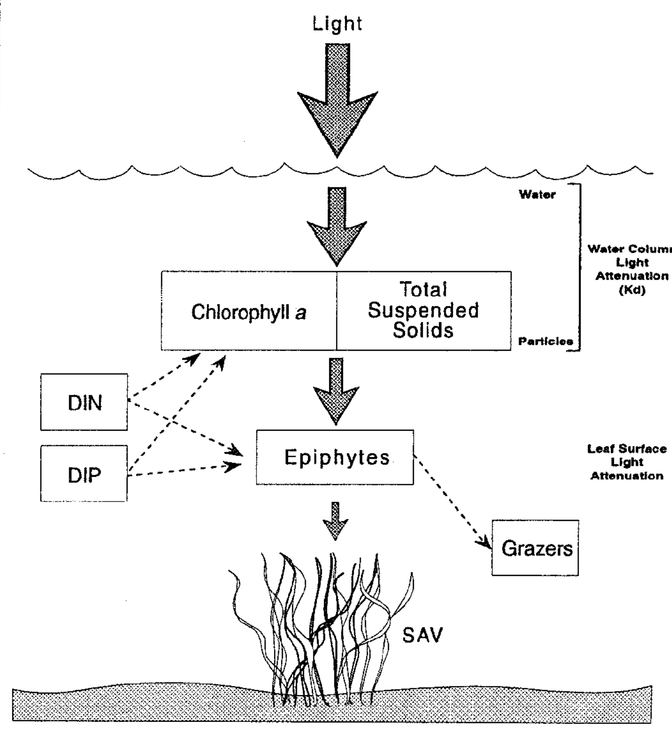

Figure 1. Availability of light for SAV is determined by light attenuation processes. Water column attenuation, measured as light attenuation coefficient (Kd), results from absorption and scatter of light by particles in the water (phytoplankton measured as chlorophyll *a*; total organic and inorganic particles measured as total suspended solids) and by absorption of light by water itself. Leaf surface attenuation, largely due to algal epiphytes growing on SAV leaf surfaces, also contributes to light attenuation. Dissolved inorganic nutrients (DIN = dissolved inorganic nitrogen; DIP = dissolved inorganic phosphorus) contribute to phytoplankton and epiphyte components of overall light attenuation, and epiphyte grazers control accumulation of epiphytes.

tific studies from around the world have established the importance of light availability as the major environmental factor controlling SAV distribution, growth, and survival. The primary environmental factors contributing to light attenuation are used to formulate SAV habitat requirements: light attenuation coefficient, chlorophyll *a*, total suspended solids, dissolved inorganic nitrogen, and dissolved inorganic phosphorus.

The minimum light requirement of a particular SAV species determines the maximum water depth for survival. This can be depicted graphically as the intersection of the light intensity versus depth curve with the minimum light requirement value (Figure 2). Light is attenuated exponentially with water depth (Figure 2, right side). The minimum light requirement of a particular SAV species, as a percent of incident light, intersects the light curve to give a predicted maximum depth of SAV survival for that species (Figure 2, left side).

Determination of Maximum Depth of SAV Survival

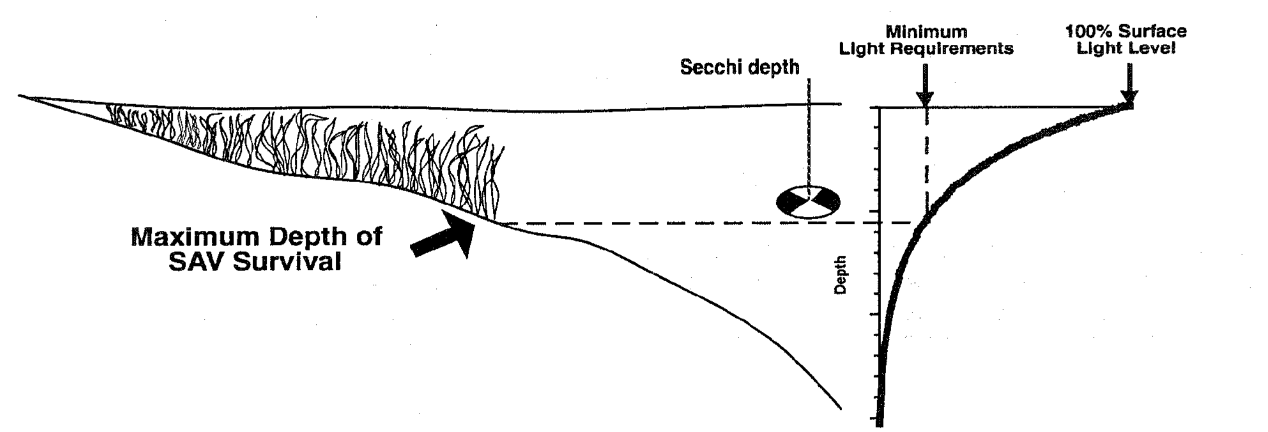

Figure 2. The interrelationships between light attenuation, SAV minimum light requirement, Secchi depth and the maximum depth of SAV survival depicted schematically. The intersection of the minimum light requirement and the light attenuation curve determines the maximum depth of SAV survival.

Four study areas were used to develop specific relationships between SAV survival and water quality (Figure 3). These study areas represent regions of intensive SAV studies over the past decade in which water quality data and SAV growth, distribution, density, and transplant data were available. Empirical relationships developed between water quality characteristics and SAV distributions provided the means of defining habitat requirements for SAV survival. It is the application of these SAV/water quality relationships, from the case studies in different regions of Chesapeake Bay by different investigators over the span of several years, that forms the basis of the SAV habitat requirements.

Locator Map of SAV Study Areas

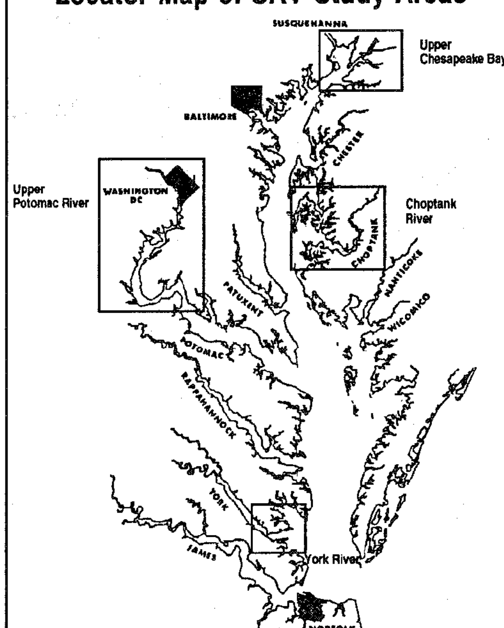

Figure 3. Locations of four regional SAV study areas-upper Chesapeake Bay, upper Potomac River, Choptank River, and the York River.

SAV habitat requirements are defined as the minimal water quality levels necessary for SAV survival. Water quality parameters used in the delineation of habitat requirements were chosen because of their relevance to SAV survival. SAV habitat requirements were formulated by: a) determining SAV distributions by transplant survival and baywide distributional surveys; b) measuring water quality characteristics along large scale transects that spanned vegetated and non-vegetated regions; and, c) combining distributional data and water quality levels to establish minimum water quality that supports SAV survival. This type of analysis (referred to as correspondence analysis) was strengthened by factors common to each of the case studies. Field data were collected over several years (almost a decade in the Potomac River) in varying meteorologic and hydrologic conditions by different investigators.

Water Quality Data Used to Develop SAV Habitat Requirements

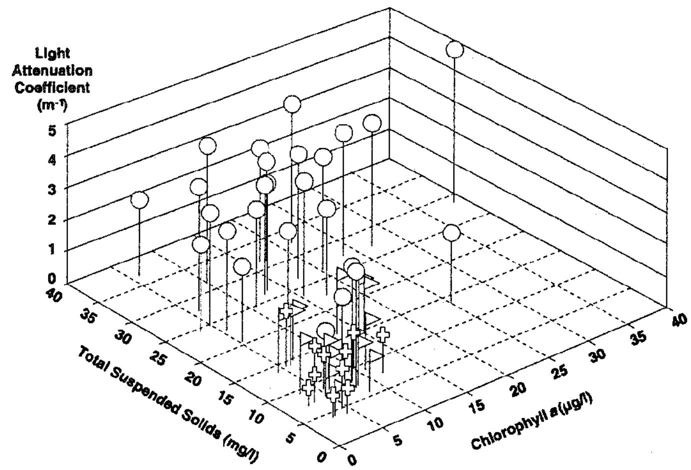

Figure 4. Three-dimensional comparisons of May-October median light attenuation coefficient, total suspended solids, and chlorophyll *a* concentrations of the Choptank River stations.

SAV distributions in the four case studies across all salinity regimes were responsive to the five water quality parameters used to develop the SAV habitat requirements. The degree of interdependence of these water quality parameters is illustrated by a three-dimensional plot of total suspended solids, chlorophyll *a*, and light attenuation coefficient for the Choptank River (Figure 4). In addition, interannual changes in water quality led to changes in SAV distribution and abundance in each region that were consistent with habitat requirements.

The diversity of SAV communities throughout Chesapeake Bay, with its wide salinity range, has led to the establishment of separate habitat requirements based on salinity regime. Water quality conditions sufficient to support survival, growth, and reproduction of SAV to water depths of one meter are used as SAV habitat requirements (Table 1).

Table 1. Chesapeake Bay SAV Habitat Requirements.

	SAV Habitat Requirements for One Meter Restoration[1] — Habitat Requirements Which Effect Water Column/Leaf Surface Light Attenuation						SAV Habitat Requirements for Two Meter Restoration[1]	
Salinity[2] Regime	**Light[3] Attenuation Coefficient (m^{-1})**	**Total Suspended Solids (mg/l)**	**Chlorophyll *a* (µg/l)**	**Dissolved Inorganic Nitrogen (mg/l)**	**Dissolved Inorganic Phosphorus (mg/l)**	**Critical Life Period**	**Light[3] Attenuation Coefficient (m^{-1})**	**Critical Life Period**
Tidal Fresh	<2	<15	<15	–	<0.02	April-October	<0.8	April-October
Oligohaline	<2	<15	<15	–	<0.02	April-October	<0.8	April-October
Mesohaline	<1.5	<15	<15	<0.15	<0.01	April-October	<0.8	April-October
Polyhaline	<1.5	<15	<15	<0.15	<0.02	March-November	<0.8	March-November

1. The SAV habitat requirements are applied as median values over the April-October critical life period for the tidal fresh, oligohaline and mesohaline salinity regimes. For the polyhaline salinity regimes, the SAV habitat requirements are applied as median values from combined March-May and September-November data. Light attenuation coefficient should be applied as the primary habitat requirement; the remaining habitat requirements should be applied to help explain regional or site specific causes of water column and leaf surface light attenuation which can be directly managed.
2. Tidal fresh = <0.5 ppt; oligohaline = 0.5-5 ppt; mesohaline = >5-18 ppt; and, polyhaline = >18 ppt.
3. To determine the Secchi depth habitat requirements, apply the conversion factor Secchi depth = 1.45/light attenuation coefficient.

For SAV to survive to one meter, light attenuation coefficients of <2 m^{-1} for tidal fresh and oligohaline regions and <1.5 m^{-1} for mesohaline and polyhaline regions were needed. Total suspended solids (<15 mg/l) and chlorophyll *a* (<15 µg/l) values were consistent for all regions. However, habitat requirements for dissolved inorganic nitrogen and dissolved inorganic phosphorus varied substantially between salinity regimes. The SAV habitat requirement for two meter restoration for light attenuation was derived using an exponential light attenuation equation which quantitatively defines the interrelationship between light attenuation, minimum light requirements, and depth penetration of SAV. The SAV habitat requirement for two meter restoration for light attenuation was determined to be Kd <0.8 m^{-1}, based on 20% surface irradiance as the minimum light requirement.

In tidal freshwater and oligohaline regions, SAV survive episodic and chronic high concentrations of dissolved inorganic nitrogen; consequently, habitat requirements for dissolved inorganic nitrogen were not determined for these regions. In contrast, maximum dissolved inorganic nitrogen concentrations of 0.15 mg/l were established for mesohaline and polyhaline regions. The SAV habitat requirement for dissolved inorganic phosphorus was <0.02 mg/l for all regions except for mesohaline regions (<0.01 mg/l). Differences in nutrient habitat requirements in different regions of Chesapeake Bay are consistent with observations from a variety of estuaries that shifts in the relative importance of phosphorus versus nitrogen as limiting factors occur over an estuary's salinity gradient.

Light attenuation, through the water column and at the leaf surface, is the principal factor influencing SAV. The light attenuation coefficient habitat requirement reflects the minimum water column light attentuation level at which SAV survive and grow. Total suspended solids and chlorophyll *a* directly influence and, therefore, can be used to explain sources of water column light attenuation. Dissolved inorganic nitrogen and dissolved inorganic phosphorus also directly affect the potential for leaf surface light attenuation through epiphytic growth. Although the light attenuation coefficient habitat requirement should be applied as the primary SAV habitat requirement, application of the remaining SAV habitat requirements will help explain regional or site specific causes of water column and leaf surface light attenuation which can be directly managed through nutrient reductions and shoreline erosion controls.

The Chesapeake Bay SAV habitat requirements developed in the four study areas were applied to the rest of the Chesapeake Bay to test the baywide correspondence of SAV distributions with the five water quality parameters measured at mid-channel monitoring stations. SAV growing season median water quality values were calculated for 105 monitoring stations in the Chesapeake Bay and its tidal tributaries for 1987 and 1989, with 1989 results summarized in Table 2.

Table 2. Application of the five SAV habitat requirements to growing season medians of data from mid-channel Chesapeake Bay monitoring stations near SAV beds in 1989. Percentages represent the frequency of stations near SAV that had the habitat requirement met, followed by the number of stations in parentheses.

Salinity	**Habitat Requirement**				
Regime	**KD**	**TSS**	**CHLA**	**DIN**	**DIP**
Tidal Fresh	100% (1)	100% (1)	100% (1)	–	100% (1)
Oligohaline	0% (1)	0% (1)	100% (1)	–	100% (1)
Mesohaline	95% (19)	79% (19)	100% (19)	68% (19)	95% (19)
Polyhaline	100% (11)	55% (11)	100% (11)	100% (11)	100% (11)
ALL	**94% (32)**	**69% (32)**	**100% (32)**	**80% (30)**	**97% (32)**

The number of stations in each salinity regime, in areas with and without SAV, was tabulated according to whether each of the five habitat requirements were met or not met. If the habitat requirements were perfect predictors of SAV growth, 100% of the stations with SAV would have met all the habitat requirements.

Table 2 shows that the five habitat requirements have slightly differing abilities to predict SAV presence: light attenuation coefficient (94%), total suspended solids (69%), chlorophyll *a* (100%), dissolved inorganic nitrogen (80%), and dissolved inorganic phosphorus (97%). The overall average (88%) for all parameters is fairly high and indicates the utility of this approach.

SAV distribution restoration targets, approached from a baywide and regional perspective, were produced through a series of geographical overlays delineating actual and potential SAV habitat (Table 3). A tiered set of SAV distribution restoration targets for areas previously vegetated between 1971 and 1990 (Tier I), one meter (Tier II), and two meter (Tier III) water depths were established to provide management agencies with quantitative measures of progress in SAV distribution in response to the implementation of Chesapeake Bay restoration strategies. Each successive target represents expansions in SAV distribution in response to improvements in water quality over time, measured as achievement of the SAV habitat requirements for one and two meter restoration.

Table 3. Chesapeake Bay SAV distribution targets and their relationships to the 1990 SAV aerial survey distribution data.

RESTORATION TARGET	DESCRIPTION	AREA (hectares)	1990 SAV DISTRIBUTION AND PERCENT OF RESTORATION TARGET
Tier I–composite beds	Restoration of SAV to areas currently or previously inhabited by SAV as mapped through regional and baywide aerial surveys from 1971 to 1990.	46,025	24,393 (53%)
Tier II–one meter	Restoration of SAV to all shallow water areas delineated as existing or potential SAV habitat down to the one meter depth, excluding areas identified as unlikely to support SAV based on historical observations, recent survey information, and exposure regimes.	In Progress	—
Tier III–two meter	Restoration of SAV to all shallow water areas delineated as existing or potential SAV habitat down to the two meter contour, excluding areas identified under the Tier II target as unlikely to support SAV as well as several additional areas between 1 and 2 meters.	247,658	24,393 (10%)

The 1990 SAV distribution data indicate that current SAV abundance (24,393 hectares) is 53% of the Tier I target and only 10% of the Tier III target (Table 3). These estimates provide a baseline on which the success of nutrient and sediment reduction strategies for the Chesapeake Bay can be assessed.

The nearshore/mid-channel water quality comparison was organized around the same four study areas. Results of this comparison indicate that mid-channel water quality data can be used to characterize nearshore areas over seasonal time frames but do not imply a predictive relationship between nearshore and mid-channel observations. Seasonal aggregations of mid-channel water quality data can provide reliable estimates of nearshore water quality conditions for the parameters examined in this study.

The technical synthesis represents a first comprehensive effort to link habitat requirements for a living resource with water quality restoration targets for an estuarine system. This habitat requirements approach, while deviating from the traditional dose/response measures and direct toxicity studies, provides testable hypotheses that can be explored in future studies in other estuaries. Additional experimental evidence using field and laboratory approaches to test the empirical relationships developed in this synthesis are necessary for development of water quality criteria, with a goal of improved predictive capacity of habitat requirements.

SAV habitat requirements represent the absolute minimum water quality characteristics necessary to sustain plants in shallow water. As such, exceeding any of the five water quality characteristics will seriously compromise the chances of SAV survival. Improvements in water clarity to achieve greater depth penetration of SAV would not only increase depth penetration, but also increase SAV density and biomass. In addition, improvements of water quality beyond the habitat requirements could lead to the maintenance or reestablishment of a diverse population of native SAV species.

We need to maintain continuous interactions and feedback between the researchers who continue to investigate SAV/water quality interactions and the managers who are responsible for ultimate protection, restoration, and enhancement of living resources. Continued research and monitoring of water quality and SAV, coupled with management towards specific restoration targets, is paramount if these resources are to be part of our future.

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Chapter I
Introduction

It is only in the Chesapeake Bay...where it (canvas-back duck) becomes itself the king of all wild fowl. This excellence is attributable solely to the peculiar food which it finds in that estuary, a plant commonly known as wild celery...This plant, of which the canvas-back duck is so fond, that it derives from it its specific name...grows on shoals where the water is from eight to nine feet in depth, which are never wholly bare...

From Frank Leslie's Illustrated Newspaper, Feb. 10, 1866

Many estuaries are experiencing water quality problems because of pressures from increasing numbers of people moving to coastal areas. Most noticeable of all the changes are declines in harvestable living resources, such as fish and shellfish. Of equal concern are losses of other critical components of the food chain that often go undetected because of inadequate resources to monitor all species. Declines of these living resources can be related to natural factors, such as climatic events, or to anthropogenic inputs, such as nutrient enrichment due to poor land use management practices or point source inputs.

The growth, distribution, abundance, and survival of any one species in a habitat is regulated by a set of requirements unique to that species (e.g., dissolved oxygen, light, and nutrients). For each particular parameter, a species survives within a range of values, above or below which that species experiences stress that may cause reduced growth and productivity or lead to death. Species survival depends on the integration of responses to all parameters that are important for its growth. Tolerances to one parameter (e.g., dissolved oxygen) may either be increased or decreased by its interaction with one or more additional parameters (e.g., temperature, salinity). Therefore, a complete understanding of the species' overall habitat requirements is critical for evaluating its response to environmental perturbations.

The Chesapeake Bay has received considerable attention over the last two decades from scientists, managers, politicians, and the public. Deterioration of water quality related to increasing nutrient enrichment, high levels of contaminants, anoxic or hypoxic conditions, and declines in living resources, are some of the major concerns facing Chesapeake Bay today. It is increasingly recognized by scientists and managers that to reach the overall goal of a clean, "healthy" Bay, establishment of goals for habitat restoration, which are built upon habitat requirements of critical species living in Chesapeake Bay, are required.

The 1987 Chesapeake Bay Agreement set as a major priority the "need to determine the essential elements of habitat quality and environmental quality necessary to support living resources and to see that these conditions are attained and maintained." The Chesapeake Bay Program's Implementation Committee called for guidelines to determine habitat requirements for the Bay's living resources. First published in 1988, the "Habitat Requirements for Chesapeake Bay Living Resources" (Chesapeake Bay Program 1988) has been revised to provide more detailed living resource habitat requirements (Chesapeake Bay Program 1991). Because submerged aquatic vegetation (SAV) was determined to be critical to the Bay's food chain, serving as food source, nursery, and potential indicator of the Bay's health due to its sensitivity to water quality (Orth and Moore 1988), it was included in both these documents as a target community of species.

SAV has received considerable attention in Chesapeake Bay over the last 20 years because of an unprecedented baywide decline of all species beginning in the late 1960s (Stevenson and Confer 1978; Orth and Moore 1983). This decline was caused by increasing amounts of nutrients and suspended sediments in the Bay resulting from continued, uncontrolled development of the Bay's shoreline and watershed and poor land use practices associated with development and agriculture (Orth and Moore 1983; Kemp *et al.* 1983).

The adoption of a Chesapeake Bay Submerged Aquatic Vegetation Policy (Chesapeake Executive Council 1989) followed by an Implementation Plan for the Chesapeake Bay Submerged Aquatic Vegetation Policy (Chesapeake Executive Council 1990) highlighted not only the need to develop SAV habitat requirements but also baywide restoration goals for SAV distribution, abundance, and species diversity. In response to the commitments described in these documents, a group of scientists and managers produced the "Chesapeake Bay Submerged Aquatic Vegetation Habitat Requirements and Restoration Targets: A Technical Synthesis."

Technical Synthesis Objectives, Content, and Structure

Synthesis Objectives

The SAV Technical Synthesis has four major objectives:

1. establish the quantitative levels of water quality parameters necessary to support survival, propagation, and restoration of SAV;

2. establish regional distribution, abundance, and species diversity targets for the Chesapeake Bay and its tributaries;

3. document the baywide applicability of habitat requirements developed through the case studies in the synthesis; and,

4. assess the applicability of mid-channel monitoring data for evaluating the water quality in adjacent shallow-water habitats.

Synthesis Content

The development of SAV habitat requirements is described through four study areas spanning all the Bay's salinity regimes. Interpretation of transplant and monitoring data from the upper Chesapeake Bay and a decade of data spanning the revegetation of the upper tidal Potomac River yielded habitat requirements for tidal fresh and oligohaline SAV species. A variety of transplant, research, and monitoring studies in the Choptank and York rivers provided data necessary to develop habitat requirements for mesohaline and polyhaline SAV species, respectively.

SAV habitat requirements were developed for each of the Bay's four salinity regimes for light attenuation coefficient, total suspended solids, chlorophyll *a*, dissolved inorganic nitrogen, and dissolved inorganic phosphorus. These habitat requirements were developed through interpretation of findings by multi-investigators from each of the four study areas. The relative importance and interactions between each of these parameters is explored through a conceptual model that characterizes the parameters direct and indirect impacts on SAV survival and growth.

SAV distribution and density restoration targets, approached from a baywide and regional perspective, were produced through a series of geographical overlays delineating actual and potential SAV habitat. The tiered distribution restoration targets are reported as acreages of shallow water Bay habitat that should support SAV if the established habitat requirements are met. Species diversity restoration targets were derived by comparing the historical, existing, and potential habitat for each species based on salinity, and the actual and potential habitat as defined through the distribution restoration targets.

The habitat requirements generated through the four study areas were applied to other regions within the same salinity regime to test whether the habitat requirements could be used for other sites throughout the Chesapeake Bay. This assessment was conducted through a comparative analysis of 1987 and 1989 water quality and SAV distribution data and the corresponding habitat requirements.

The nearshore/mid-channel water quality comparison is organized around the same four study areas described above and compares medians of April-October data for each of the parameters analyzed for habitat requirements. This time period covers the critical life stages for most Chesapeake Bay SAV species.

Synthesis Structure

This technical synthesis is structured to provide the reader with an expanded summary of both the SAV habitat requirements and restoration targets in the beginning of the document (Chapter IV). Preceding the SAV habitat requirements and restoration targets summary are descriptions of SAV and water quality relationships (Chapter II) and the habitat requirements development approach (Chapter III). The more detailed description of the information, which went into development of the habitat requirements (Chapter V) and restoration targets (Chapter VI), is followed by results from the nearshore/mid-channel comparisons (Chapter VII). Finally, future research needs for SAV are outlined (Chapter VIII). Appendices include copies of the more extensive tables, figures, and maps referred to within the technical synthesis.

Chapter II

SAV and Water Quality Relationships

Worldwide, populations of submerged aquatic vegetation in freshwater, estuarine, and marine habitats have been affected by human activities. In particular, environmental perturbations resulting in reductions of light available to SAV have been implicated in numerous SAV declines (den Hartog and Polderman 1975; Peres and Picard 1975; Orth and Moore 1983; Kemp *et al.* 1983; Cambridge and McComb 1984). The central role of light availability in SAV growth has been demonstrated in numerous field, laboratory, and modeling studies. The interrelationships between nutrient enrichment, suspended sediments, and light attenuation are the subject of various conceptual models (Wetzel and Hough 1973; Phillips *et al.* 1978).

The composition of the primary producers along a nutrient enrichment gradient has transformed an SAV-dominated ecosystem to a phytoplankton-dominated ecosystem due to nutrient enrichment increases (Figure II-1). The impact of nutrient enrichment is indirect in that increased nutrients stimulate SAV growth. An overabundance of nutrients, however, leads to increased light attenuation and subsequent reduction of SAV growth and survival (Figure II-2). The effects of nutrients and suspended solids on light attenuation are reviewed and developed in a conceptual model which is discussed later in this chapter.

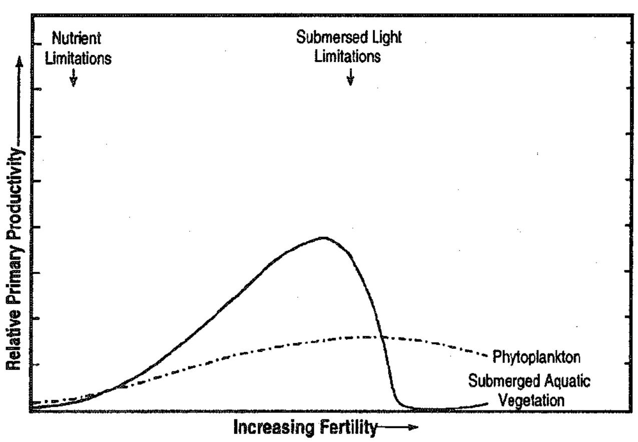


Figure II-1. Generalized relationship of primary productivity of submerged aquatic vegetation and phytoplankton of lakes during increasing fertility of the whole lake ecosystem. Reproduced from Wetzel and Hough 1973.

SAV/Water Quality Investigations

Freshwater, Estuarine, and Marine SAV

Freshwater, estuarine and marine SAV have adapted to similar environmental conditions in their subtidal habitats. As a result, they are often grouped together taxonomically even though the evolutionary relationships between these plants have not yet been established (Stevenson 1988). Since Chesapeake Bay is an estuary that has a salinity range spanning freshwater, estuarine, and marine conditions, the potential differences between these plants and the characteristic environmental conditions of freshwater to marine habitats must be recognized in the development of habitat requirements.

In a comparative review of SAV, Stevenson (1988) summarized the differences in the physical and chemical regimes of freshwater, estuarine, and marine habitats. Important differences were found between freshwater, estuarine, and marine SAV. Freshwater SAV tends to have shorter growing seasons than estuarine and marine species. Hence, in Chesapeake Bay, critical growing periods were determined separately for the various salinity regimes. The biomass of marine SAV can be higher than freshwater SAV, particularly in terms of below-ground relative to above-ground structures (resulting in a higher root-to-shoot ratio). Since the below-ground tissues provide a storage reservoir of carbohydrates that can be utilized under reduced light conditions, marine SAV, in general, may be better able to tolerate short-term reductions of light availability than many freshwater SAV. Overall, low light availability in estuarine habitats accounts for the high susceptibility of these plants.

Depth Penetration

Despite the differences between freshwater, estuarine, and marine SAV and their habitats, the relationships between light availability and the depth to which SAV will grow (SAV depth penetration) in these habitats are similar in shallow, turbid waters. The maximum depth penetration of a diversity of freshwater SAV species from a variety of

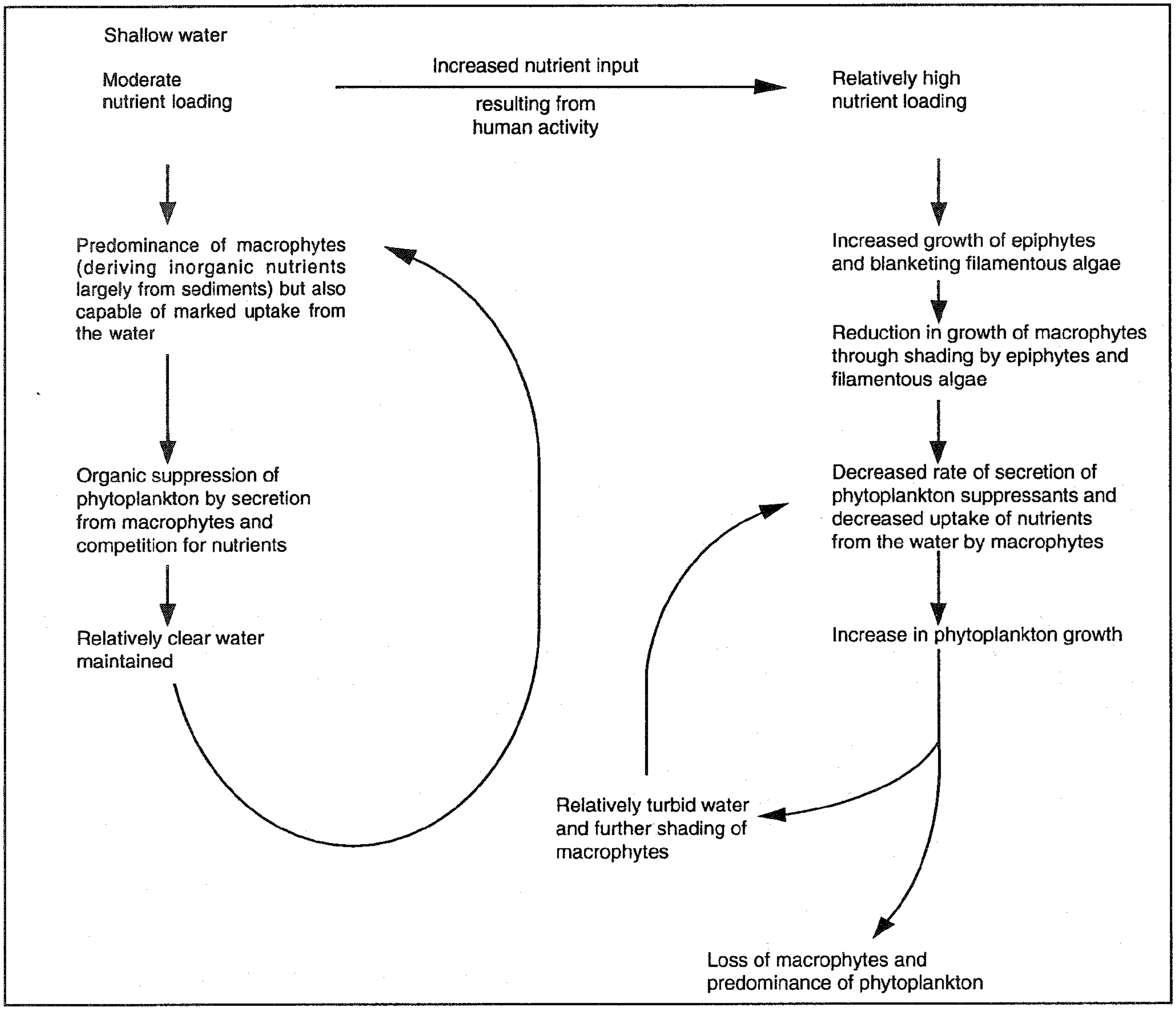


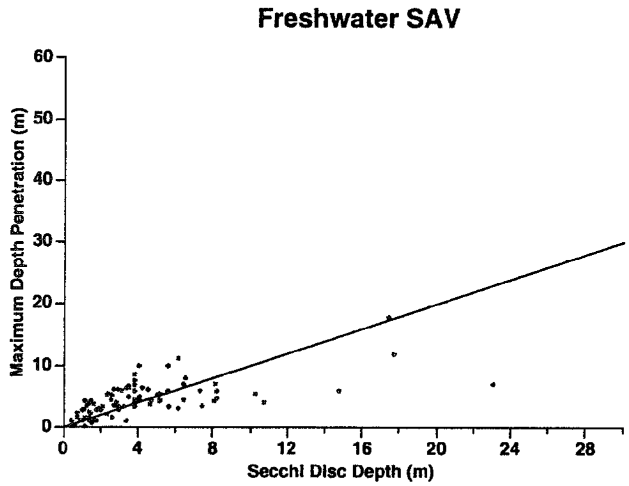
Figure II-2. Hypothesis to account for declines in SAV populations when water bodies become nutrient enriched. Reproduced from Phillips *et al.* 1978.

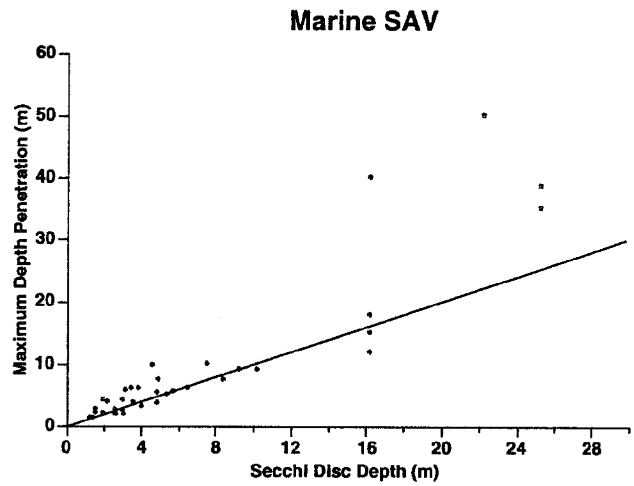
lakes is slightly greater than the Secchi depth in shallow waters (<5 m) (Figure II-3), while the maximum depth penetration is less than the Secchi depth in deeper waters (>5 m). The maximum depth penetration of a diversity of marine SAV species from a variety of coastal marine environments is roughly equivalent to the Secchi depth throughout a wide depth range (Figure II-4).

The divergence of freshwater SAV depth penetration from the 1:1 line of depth penetration and adherence of marine SAV to the 1:1 line could be due in part to the differences in canopy structure or plant architecture of many of the species. Canopy-forming SAV, common in freshwater, can grow to the water's surface in shallow areas, thereby avoiding the effect of light reductions due to water column light attenuation. On the other hand, meadow-forming SAV, common in estuarine and marine habitats, are unable to grow to the water's surface and overcome light limitation. In the next chapter, a model of SAV/light interactions is constructed for freshwater and estuarine/marine SAV based on the overall patterns of plant response to light regime in conjunction with the caveat of differences in plant architecture.

SAV Declines

SAV declines have been reported in scientific literature from around the world. Well-documented case studies from Europe (Giesen *et al.* 1990), North America (Costa 1988), and Australia (Cambridge and McComb 1984) have demonstrated the ubiquitous nature of the problems associated with nutrient enrichment in coastal waters and





Figures II-3 and II-4. Maximum depth penetration of freshwater (II-3) and marine (II-4) submerged aquatic vegetation plotted as a function of Secchi depth. The 1:1 line of maximum depth penetration and Secchi depth is plotted for reference. Data from Canfield *et al.* 1985; Chambers and Kalff 1985.

SAV declines. In addition, lake fertility studies have similarly demonstrated the negative effects of eutrophication on SAV (Moss 1976; Jupp and Spence 1977). In many areas, nutrient enrichment is a result of nonpoint sources which are difficult to quantify and identify. In a particularly well-documented case in Australia (Cambridge *et al.* 1986), however, quantifiable point source nutrient enrichments were directly linked to seagrass declines and phytoplankton blooms (Figures II-5 and II-6).

In Chesapeake Bay, SAV declines have occurred in all reaches of the estuary, from tidal fresh to polyhaline regions (Orth and Moore 1983). SAV resurgences were recently observed in some areas of Chesapeake Bay (Carter and Rybicki 1986; Orth and Nowak 1990), but SAV abundance still remains near its lowest levels in recorded history.

Agricultural development and urbanization of the Chesapeake Bay watershed have led to increases in sediment runoff and nutrient loadings, causing declines in water quality and, thereby, affecting SAV (Figure II-7). Most of the nutrient and sediment inputs to Chesapeake Bay are derived from nonpoint sources which make quantifying historical patterns of water quality difficult. The well-documented, baywide SAV declines, however, give evidence

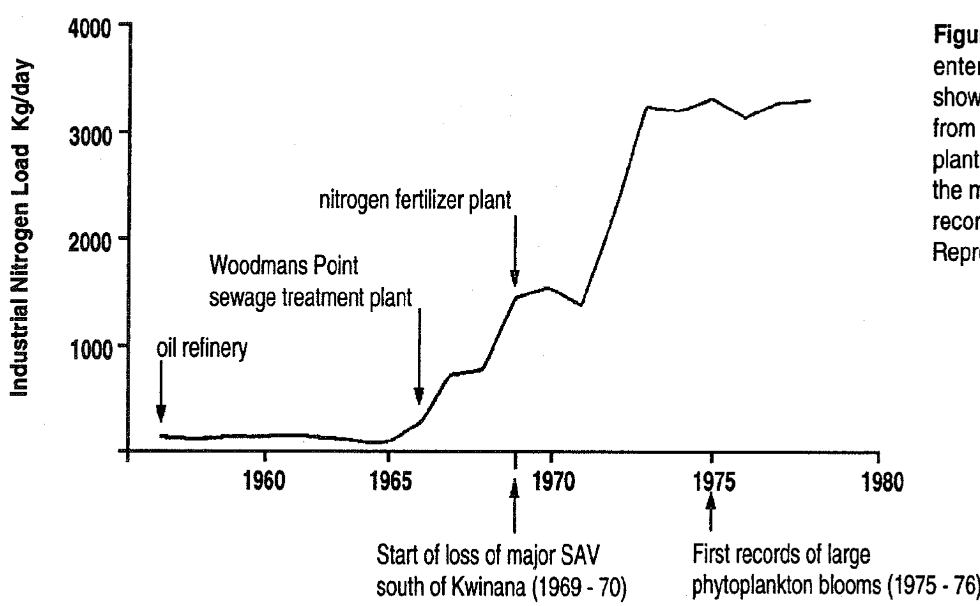


Figure II-5. Estimated nitrogen loads entering Cockburn Sound, Australia, showing the commencement of discharge from the oil refinery, sewage treatment plant, and fertilizer works, together with the major time of SAV loss and the first record of marked phytoplankton blooms. Reproduced from Cambridge *et al.* 1986.

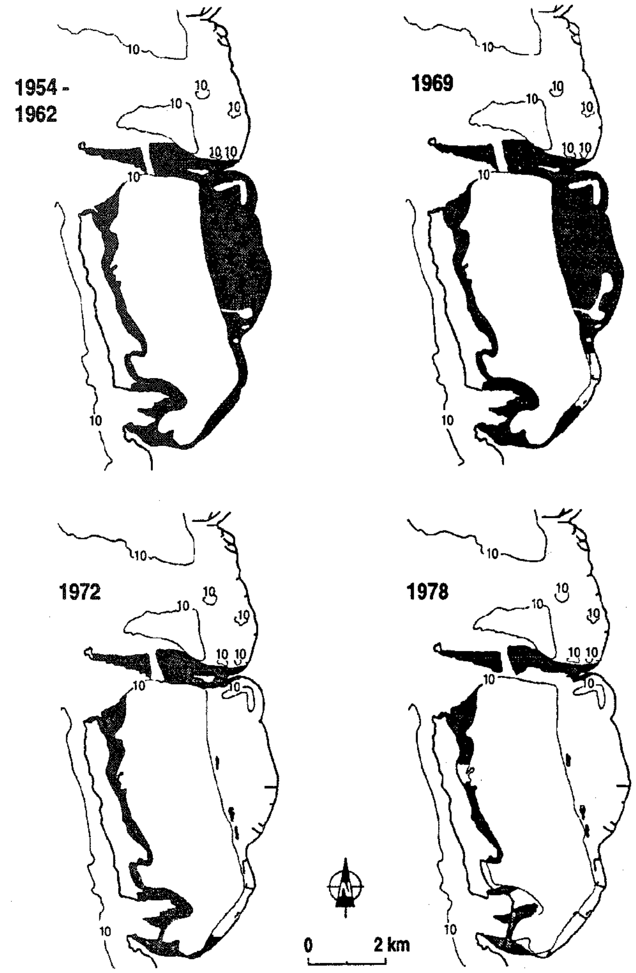


Figure II-6. Each map shows Cockburn Sound, Australia, surrounded by the coast of the mainland to the right and Garden Island to the left. The 10 m contour line is indicated. The shading shows the area of SAV meadows present at different times. Reproduced from Cambridge and McComb 1984.

for the changes in historical patterns of water quality. Experimental mesocosms were also used to test SAV responses to increased nutrient loadings in Chesapeake Bay (Kemp *et al.* 1983). Results indicated correlations between SAV declines and large increases in nutrient loading rates and epiphyte and phytoplankton biomass (Figure II-8).

Light Relationships

The low light environments of estuaries have led to various SAV adaptations, such as pigment composition changes and biochemical and structural adaptations, which allow the plants to better tolerate some of the suboptimal light conditions (Spence 1975; Bowes *et al.* 1977; Wiginton and McMillan 1979; Dennison and Alberte 1986). In spite of these adaptations, evidence demonstrating light limitation of SAV growth has been obtained through experimental *in situ* manipulations of light intensity (Backman and Barilotti 1976; Bulthuis 1983; Dennison and Alberte 1985; Williams and Dennison 1990).

Variations in year-to-year light availability leading to changes in SAV abundance have been reported for tidal fresh (Carter and Rybicki 1990) and marine SAV (Wetzel and Penhale 1983) in Chesapeake Bay. In addition, a model was developed that relates instantaneous photosynthetic responses of a marine SAV species, *Zostera*

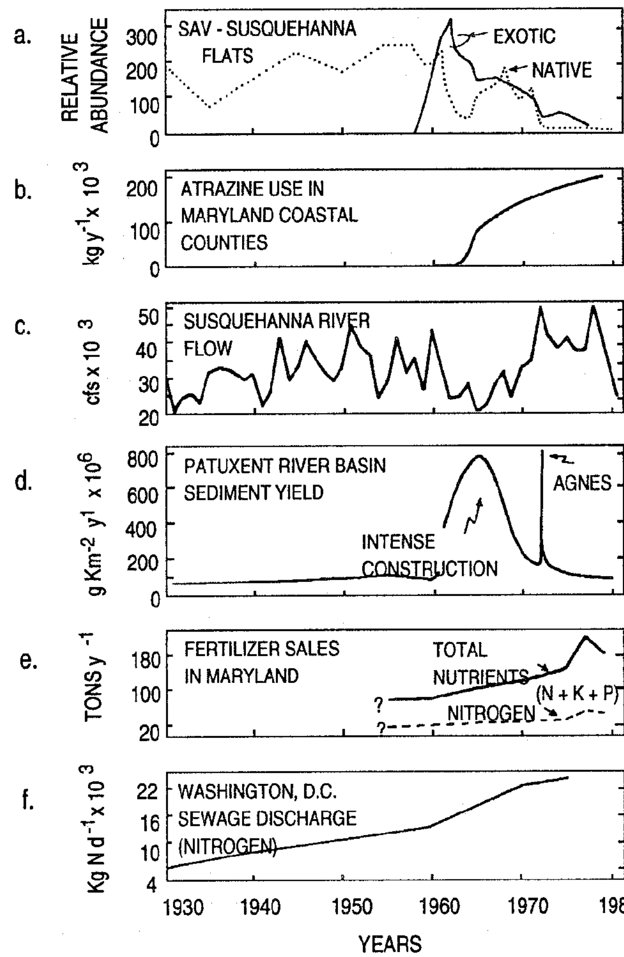


Figure II-7. Summary of long-term trends (1930-1980) in selected variables for Chesapeake Bay and its tributaries: (a) relative SAV abundance in the upper Bay; (b) use of atrazine in coastal plain counties draining into the Bay; (c) Susquehanna River flow; (d) idealized sediment yield for Patuxent River Basin; (e) fertilizer sales in Maryland; (f) nitrogen in sewage discharge from Washington D.C. into the Potomac River estuary. Reproduced from Kemp *et al.* 1983.

marina, to light availability, providing a means of relating changes in light attenuation to changes in SAV productivity and depth penetration (Dennison 1987). This model (H_{sat}/H_{comp}) provides a predicted relationship between light attenuation coefficient (Kd) and maximum depth limit of SAV in which the depth limit (in m) is equal to 1.6/Kd (Figure II-9).

Epiphyte/Grazing Interactions

Epiphytic growth on SAV leaves contributes to reductions in light reaching the plants' leaf surfaces. Epiphyte grazing by herbivorous invertebrates, such as snails and isopods, decreases the accumulation of epiphytes thereby reducing leaf surface light attenuation and promoting SAV growth and biomass (Orth and van Montfrans 1984). As such, the interactive effects of grazing and light attenuation on SAV growth and biomass contribute to the overall SAV response.

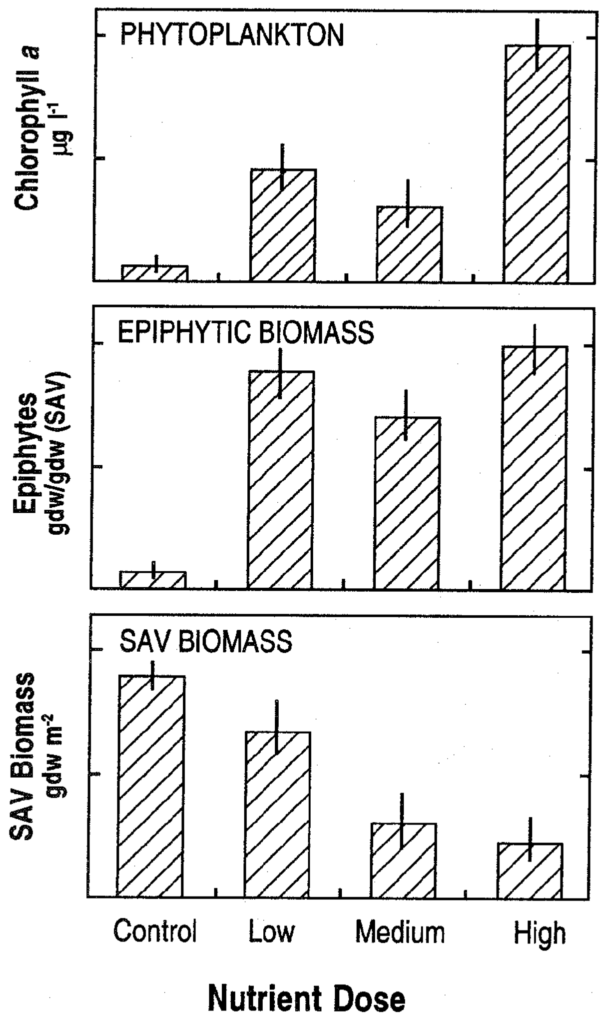


Figure II-8. Summary of phytoplankton stocks (as chlorophyll *a*), weight of epiphytic material, and SAV biomass in August 1981, for experimental ponds treated with four levels of nutrient enrichment after eight weeks. Plotted as means ± 1 standard error. Reproduced from Kemp *et al.* 1983.

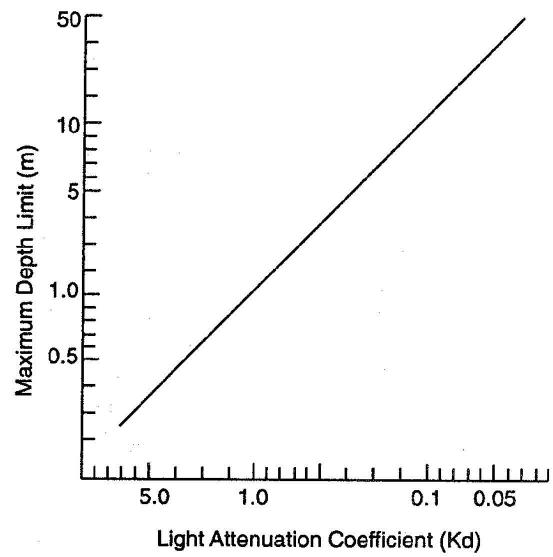


Figure II-9. Relationship between maximum depth limit (Zc) of *Zostera marina* and light extinction coefficient using a log—log plot. Equation of the line is Zc = 1.62/Kd. Reproduced from Dennison 1987.

A simulation model of SAV production, calibrated with data from Chesapeake Bay polyhaline SAV studies, was developed to predict long-term changes in SAV (Wetzel and Neckles 1986). The epiphyte, grazer, and light attenuation interactive effects on SAV were explored using this model (Figure II-10 and Table II-1). The model predicts that increased grazing intensity promotes a higher SAV tolerance to decreased water column light availability (e.g., increased light attenuation coefficient). Simulations incorporating nutrient enrichments indicate that the combined stress of nutrient enrichment and lack of grazing was most detrimental to SAV (Neckles 1990). Some of the differences between the resultant SAV habitat requirements for tidal fresh, oligohaline, mesohaline, and polyhaline regions, reported in Chapter IV, may be the result of differences in epiphyte grazing intensity.

Conceptual Model of SAV/Habitat Interactions

A conceptual model of the interactions and interdependence of the SAV habitat requirements, displayed as Figure II-11, illustrates the water quality parameters that influence SAV distribution and abundance. Light is the major environmental factor directly controlling SAV distribution (Kemp *et al.*

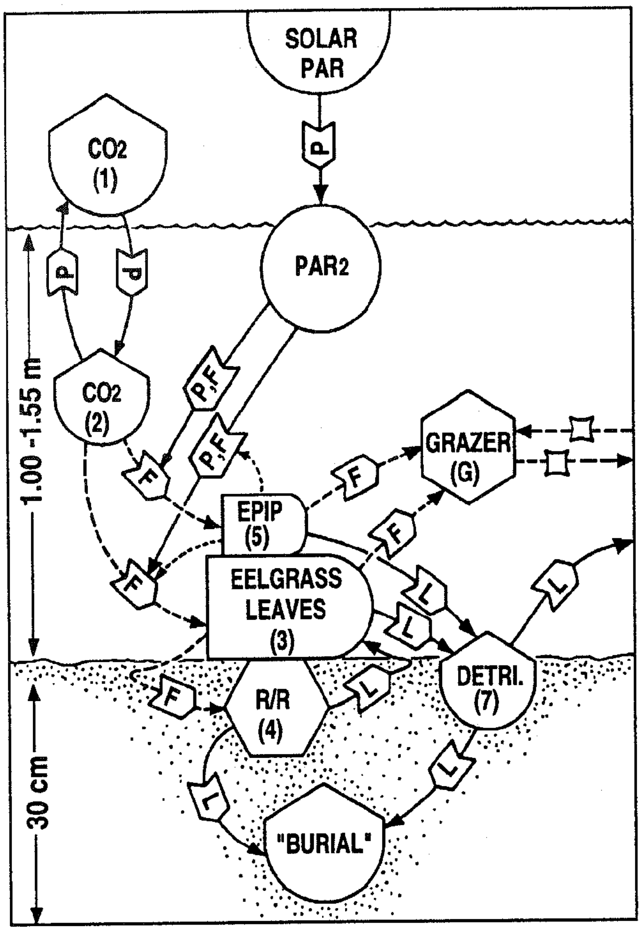


Figure II-10. The compartmental design and flow structure of a simulation model of *Zostera marina* production. For the biotic compartments, solid lines represent linear, donor controlled pathways and dashed lines represent non-linear, donor controlled pathways. Letters in the open arrows on the pathways indicate controls: P = physical-chemical; L = linear, donor controlled; F = non-linear, feedback controlled; and, R/R = roots/rhizomes. Reproduced from Wetzel and Neckles 1986.

1983; Wetzel and Penhale 1983; Dennison 1987). Light attenuation processes relevant to SAV fall into two major categories: attenuation occurring in the overlying water column and attenuation resulting from the layer of epiphytes and other materials on the plant's leaves.

Water Column Light Attenuation

Light attenuation (reduction in light intensity) in the water column occurs as a result of scattering and absorption of light by water molecules, dissolved substances, and suspended particles. Light attenuation by water molecules is relatively insignificant in the shallow, turbid waters of estuaries. In contrast, particles and dissolved substances in the water column can contribute substantially to light attenuation in estuaries. Light absorption by organic and inorganic particles (e.g., suspended sediments) is inferred from measurements of total suspended solids. Light absorption and scattering by organic particles (e.g., phytoplankton) is inferred by measurements of chlorophyll *a*.

The integration of all water column light attenuation, including particulate light absorption components, total suspended solids and chlorophyll *a*, is performed by directly measuring the water column light attenuation. This measurement is obtained by either lowering a Secchi disk through the water column until it becomes invisible (Secchi depth) or by lowering a light meter through the water column and calculating light attenuation coefficients based on an exponential decay function. The conversion between Secchi depth and light meter measurements is discussed in Chapter III.

A caveat in interpreting light attenuation is that chlorophyll *a* values do not always accurately depict the phytoplankton

Table II-1. Maximum annual *Zostera marina* leaf biomass (g C m^{-2}) during 10-year model simulations under various combinations of water column light attenuation and grazing intensity. Asterisks indicate loss of the community. Reproduced from Wetzel and Neckles 1986.

	Light Attenuation Coefficient (m^{-1})			
Grazing (% nominal)	1.00	1.25	1.50	1.75
100	141	136	107	*
50	135	123	69	*
25	113	69	*	*
10	105	53	*	*

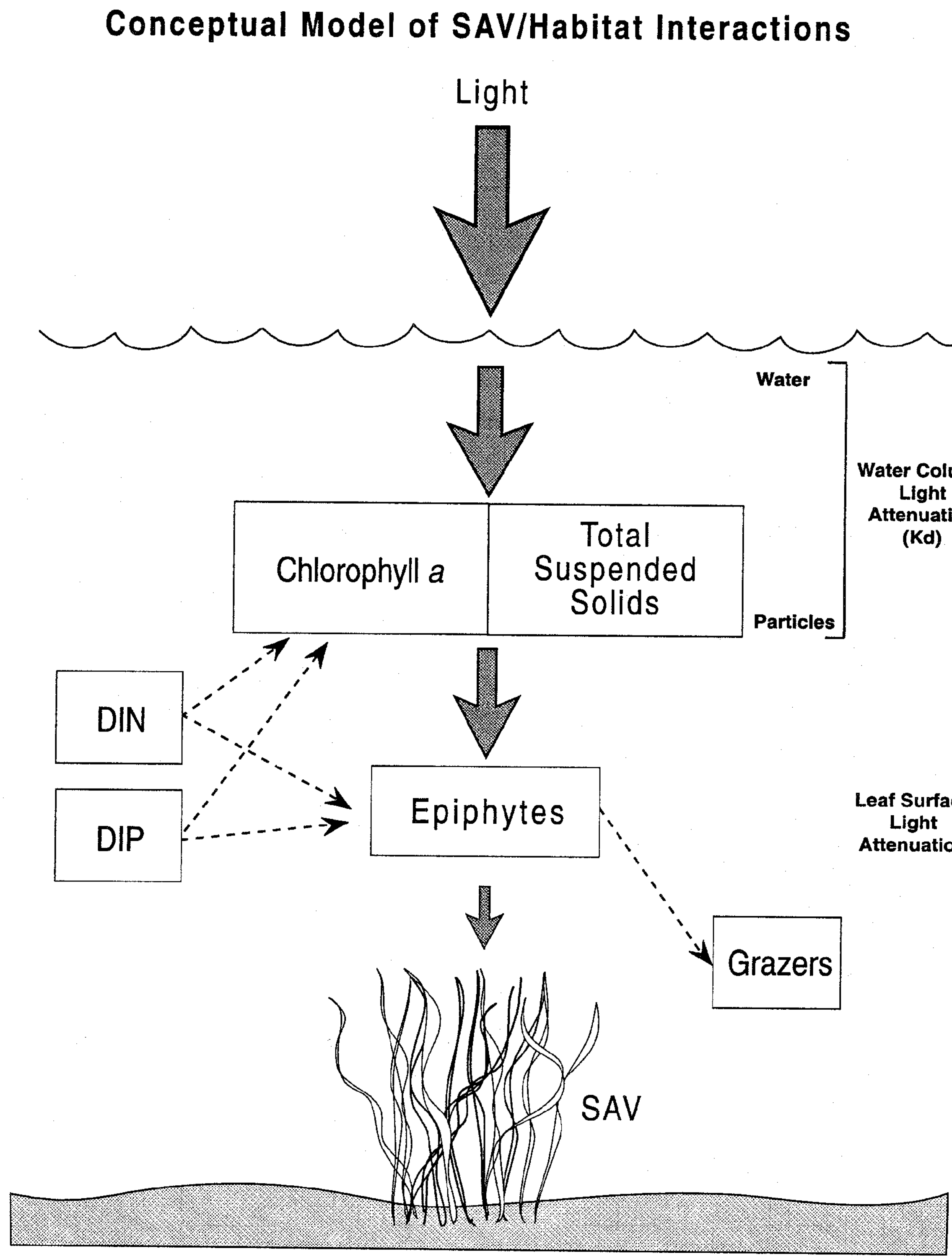


Figure II-11. Availability of light for SAV is determined by light attenuation processes. Water column attenuation, measured as light attenuation coefficient (Kd), results from absorption and scatter of light by particles in the water (phytoplankton measured as chlorophyll *a*; total organic and inorganic particles measured as total suspended solids) and by absorption of light by water itself. Leaf surface attenuation, largely due to algal epiphytes growing on SAV leaf surfaces, also contributes to light attenuation. Dissolved inorganic nutrients (DIN = dissolved inorganic nitrogen; DIP = dissolved inorganic phosphorus) contribute to the phytoplankton and epiphyte components of overall light attenuation, and epiphyte grazers control accumulation of epiphytes.

light absorption characteristics. There are several reasons for this lack of correspondence: 1) chlorophyll *a* is only one of many light absorbing pigments present in estuarine phytoplankton; 2) chlorophyll *a* is contained in phytoplankton cells of varying sizes (the "packaging effect"), affecting light absorption characteristics; and, 3) the amount of chlorophyll *a* can be highly variable due to adaptive responses, spatial and temporal heterogeneity, and measurement technique. Despite these shortcomings, the measurement of chlorophyll *a* is used because chlorophyll *a* is present in all major groups of phytoplankton and is the standard method for estimating phytoplankton biomass.

Leaf Surface Light Attenuation

The other component of light attenuation crucial to SAV is the attenuation by epiphytes and particles on the leaf surfaces. The growth of epiphytes and subsequent shading of SAV has been implicated in the 1970s declines of SAV in Chesapeake Bay (Orth and Moore 1983; Kemp *et al.* 1983). Mesocosm and laboratory studies have borne out the relationship of nutrient loadings stimulating epiphyte growth on SAV leaves with resulting shading and die-back of SAV (Twilley *et al.* 1985). The light shading effect of epiphytes has been directly measured by Carter *et al.* (1985), who found that light transmittance through artificial substrates was reduced to as little as 6% by epiphyte growth. A few studies have demonstrated that light attenuation through epiphyte shading can exceed light attenuation by the water column, especially in the shallow waters of Chesapeake Bay (Staver 1985).

Epiphytes on SAV leaves not only increase light attenuation but inhibit diffusion of substances into and out of the leaves. This thickening of the leaf boundary layer reduces the availability of key substances involved in metabolism; and, concurrently, decreases the mechanisms that remove metabolism by-products. In the low light of a turbid estuary such as Chesapeake Bay, the principal effect of epiphytes is to reduce light available for SAV photosynthesis. When light is limiting, as it often is for SAV in Chesapeake Bay (Wetzel and Penhale 1983), then the effect of epiphytes on light availability is the relevant part of the SAV/light attenuation interaction.

Algal epiphytes must obtain nutrients, such as nitrogen and phosphorus, in combination with carbon dioxide and light to achieve balanced growth. The principal sources for light (sun) and carbon dioxide (dissolved as CO_2 or HCO_3 in the water) are the same for SAV and epiphytes. SAV and epiphytes differ, however, in their ability to extract nutrients from the sediments. SAV have successfully adapted to exploit nutrient-rich sediments by absorbing nutrients through their roots and translocating them to the aboveground portions of the plant. SAV can also obtain nutrients from the water column by leaf uptake (Couginar and Kalff 1980; Thursby and Harlin 1982). Epiphytes, in contrast, do not have access to the sediment pore water nutrients except through small amounts of leakage from SAV (McRoy and Goering 1974).

Increases in water column nitrogen and phosphorus can stimulate algal epiphyte growth on SAV leaves (Borum 1985). Sand-Jensen and Sondergaard (1981) observed epiphyte biomass increase 200-fold as a result of nutrient enrichment in Danish lakes. In Chesapeake Bay mesocosm experiments, increased epiphyte biomass, resulting from nutrient additions, led to reduced SAV growth and biomass (Twilley *et al.* 1985). Additionally, the community structure of the epiphytic algae changes in response to nutrient loading. Higher nutrient enrichment levels often lead to epiphytic algal communities dominated by species other than the "typical" diatom dominated assemblages (Moss 1976). Regardless of the species composition, the increased epiphyte biomass resulting from nutrient additions leads to reductions in light available for SAV photosynthesis (Sand-Jensen 1975). Further light reductions to plants that are already living in a turbid estuary can result in senescence of plant tissue and eventual population declines.

Grazing by herbivorous invertebrates is an important control of epiphyte biomass and productivity. Snails (e.g., *Bittium varium*) and isopods can enhance SAV growth and survival by cropping epiphytes (van Montfrans *et al.* 1982). In the absence of epiphyte grazers, a rapid build-up of epiphytes on SAV leaves can occur in eutrophied areas (Howard and Short 1986). Experiments have shown that a five-fold greater above ground biomass of *Z. marina* is possible in treatments with epiphyte grazers present than in treatments without grazers (Hootsmans and Vermaat 1985). These results suggest that suppression of epiphyte biomass by grazing epifauna is an important factor in the maintenance of growth, productivity, and depth distribution of SAV, particularly in light-stressed and nutrient-enriched portions of the estuary (van Montfrans *et al.* 1982). If grazing can keep up with increased epiphyte growth, biomass does not accumulate and leaf surface light attenuation by epiphytes does not increase.

There are many estuarine examples where grazing does not keep up with epiphyte growth. Several factors contribute to the lack of grazer control of epiphyte populations. One is the reduced diversity of grazers in estuarine habitats. The variable and low salinities of the estuary restrict the grazer species diversity of invertebrates, presumably due to osmoregulation demands. The life cycle considerations and population fluctuations associated with each grazer species, therefore, contributes to uneven grazing pressure on epiphytes, allowing buildup of epiphyte biomass. Another consideration is the change in species composition of algal epiphytes as a result of nutrient enrichments (Kemp *et al.* 1988). These changes in species composition can result in less palatable species predominating (Nuendorfer 1990).

The effect of water column nutrients relative to SAV growth may be through the accumulation of epiphytes as well as through phytoplankton growth. The interaction between nitrogen and phosphorus in controlling the productivity of SAV and SAV epiphytes is crucial in determining and ultimately predicting eutrophication effects on Chesapeake Bay. Few research studies have directly addressed the nitrogen and phosphorus interaction aspect of the SAV/epiphyte relationship.

In contrast, the interaction of nitrogen and phosphorus has been studied extensively with respect to the role of the nutrients as limiting factors for SAV growth and biomass. This illustrates the apparent paradox that exists between SAV and nutrients. On one hand, sufficient nutrients are necessary for the growth and survival of SAV; yet, on the other hand, nutrient concentrations that are too high promote phytoplankton and epiphyte growth that inhibit SAV growth through water column and leaf surface light attenuation, respectively. Various studies have established nitrogen as a major limiting factor for the growth of marine SAV (reviewed in Dennison *et al.* 1987), while phosphorus is often thought to be the major limiting factor for freshwater SAV (reviewed in Howarth 1988). SAV in Chesapeake Bay, which spans tidal fresh to polyhaline salinity regimes, has a mixed response to nutrient additions, reflecting an interactive role of nitrogen and phosphorus (Murray *et al.* in review).

Chapter III

SAV Habitat Requirements Development

In the late 1980s, Chesapeake Bay submerged aquatic vegetation (SAV) investigators were presented with a question at a Living Resources Habitat Requirements Development Workshop designed to elicit the water quality requirements of key SAV species. The question was: What are the habitat requirements necessary for the restoration of SAV in Chesapeake Bay? The majority of results from experimental work in Chesapeake Bay concluded that light limitation, due to nutrient enrichment and elevated suspended sediments, was the primary habitat quality issue facing SAV in the Bay.

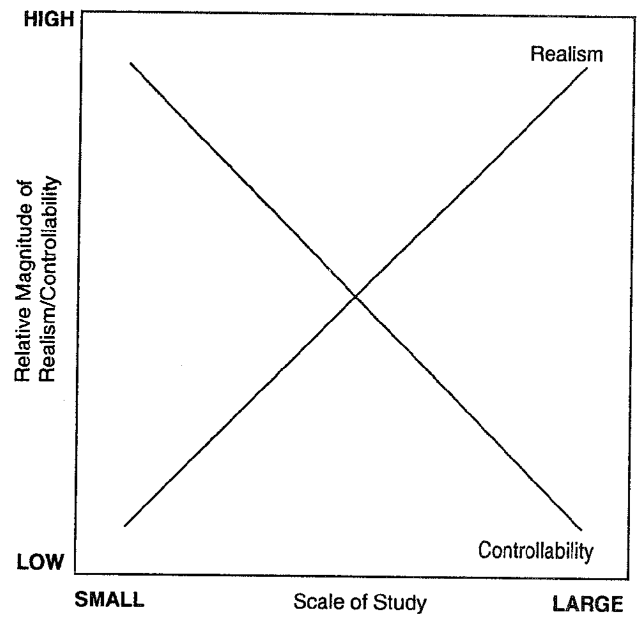


Figure III-1. Relative magnitudes of realism, controllability, and generality in research systems at various scales in a hierarchical scheme. It is conjectured that controllability decreases with increasing scale, whereas realism and generality increase with scale, and generality can be extended somewhat by performing multiple experiments and by building generic mathematical models of systems being investigated. Modified from Kemp *et al.* 1980.

Approach to Development of SAV Habitat Requirements

Rationale for Empirical Approach

Until the SAV Technical Synthesis, no direct efforts were made to quantify the actual ambient light levels and concentrations of total suspended solids, chlorophyll *a*, and nutrients necessary for SAV survival and growth in different regions of the Bay. This is mainly because many of the investigations into SAV/water quality interactions had been carried out in microcosms and mesocosms, which differ considerably from the real world.

This inconsistency is a continual problem in the environmental sciences, making the ultimate test of scientific knowledge a decision of how it can be used to make predictions about the real world. Kemp *et al.* (1983) have emphasized the trade-off in realism and controllability at various hierarchical scales in ecological investigations of complex systems in Figure III-1. Although it is possible to decouple parts of the system and replicate it for detailed studies, there is a lack of generality because the system no longer functions in its original configuration.

The pond mesocosm experiments, carried out at the University of Maryland Horn Point Environmental Laboratory (HPEL) in the early 1980s, are prime examples of the problems of scale in investigating and quantifying SAV/ water quality relationships. These experiments showed that even low additions of nitrogen and phosphorus pumped into the ambient pond waters from the nearby Choptank River were enough to cause a 50% reduction in SAV biomass. The ponds lacked realism, however, in several key aspects. One problem was the sediments. The sand in the bottom of the ponds, dredged from the Choptank River, was allowed to leach out several years before the experiment started. In contrast, the Bay's sediments have a much higher organic and nutrient content in the interstitial waters because they are continually equilibrating with overlying waters. Due to leaching, the nutrient additions to the ponds were quickly absorbed by the sediments over a number of days (Figure III-2). Although this high rate of absorption could occur in certain situations after storm events, it has not been observed in the field. Another problem with the ponds was the lack of wave activity which

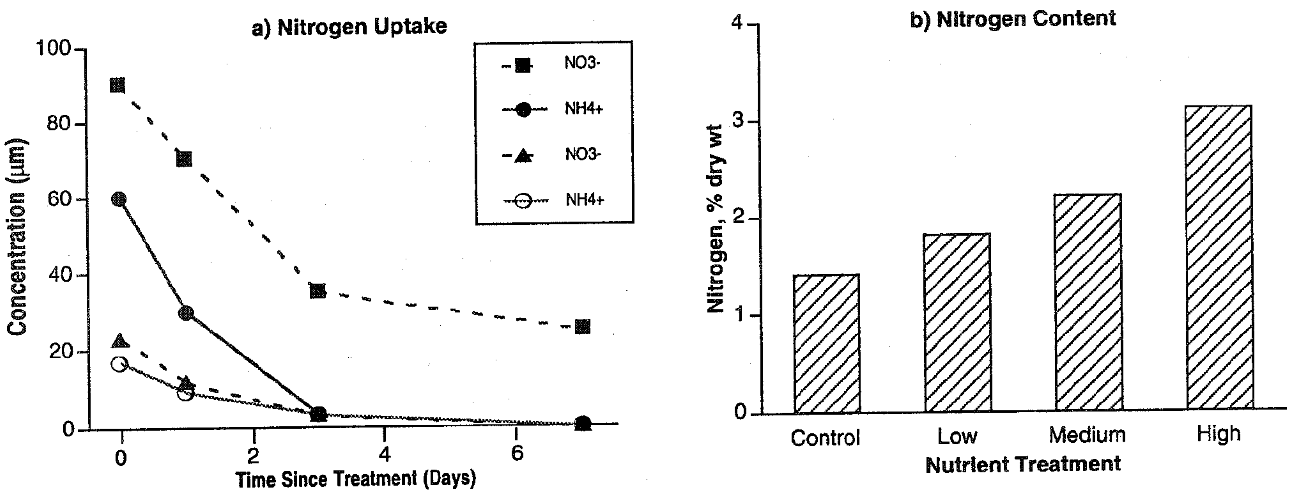


Figure III-2. Figure (a) shows the removal of NH_4 and NO_3 from the water column in enriched treatments (■ and ●) and control treatments (▲ and ○). Figure (b) shows the incorporation of nitrogen into plant tissue for experimental pond ecosystems containing SAV and treated with 3 levels of nutrient enrichment (plus controls). Reproduced from Kemp *et al.* 1984.

significantly increases normal water column turbulence. Not only were the ponds more stratified than the Bay, but their sediments never resuspended. There was also little sediment input to the ponds due to reservoir filtration.

Scientists are trained to make interpretations based on "hard inference," where a particular experiment or line of experiments eliminate alternative hypotheses about the behavior of a system. Because of the potentially important differences between mesocosms and nature, the investigators were reluctant to answer questions of what (and which) nutrient concentrations were detrimental to the Bay's SAV. Their modeling approaches, used as an extension of pond and lab experiments (e.g., Wetzel and Neckles 1986), never predicted what concentrations of nitrogen and phosphorus were problematic for SAV in the field. What was lacking was information from "soft inference."

Correspondence Between SAV/Water Quality Gradients

"Soft inference" requires inspiration (Beveridge 1950) as well as intensive detective work involving probabilities that are akin to the well accepted epidemiologic studies in medicine that originated over a hundred years ago (Glass 1986). In this study, there are four independent sets of multi-year field observations which corroborate laboratory and mesocosm findings.

The SAV habitat requirements, developed through the analysis of findings from the four case study sites, are based on field validation of SAV/water quality relationships initially defined through years of laboratory and mesocosm studies and qualitative insights into SAV habitat requirements. Since natural interactions between all the parameters could not be modeled in a laboratory setting or even in pond mesocosm, no quantitative habitat requirements resulted. By focusing intensive field investigations along an SAV/water quality gradient, the principal investigations were able to quantify SAV/habitat quality interactions.

The basis for quantifying SAV habitat requirements–correspondence analyses of SAV distribution and abundance with water quality gradients–was strengthened by two components within each of the case studies. First, field data has been collected over several years (almost a decade in the Potomac) of varying meteorologic and hydrologic conditions. Second, the findings from the four case studies, across all salinity regimes, were similar for light attenuation coefficient, total suspended solids, and chlorophyll *a*–consistent total suspended solids and chlorophyll *a* results were anticipated due to their close interaction with water column light attenuation.

Use of SAV Transplants in Habitat Requirement Development

The discovery that SAV can be successfully transplanted if the water quality is adequate led to the idea of using transplants as mini-experiments to determine if the water quality could support SAV growth. Transplants were used because natural regrowth might be limited by the availability of seed and/or overwintering vegetative material for early spring growth. If the transplants flourished in a particular area, it validated the hypothesis that the water quality was sufficient for SAV growth and survival. At first, transplanting was viewed only as a potentially important tool in restoring SAV to previously unvegetated sites. However, when used over a number of sites throughout the estuary, transplanting was found to be very useful in determining water quality thresholds necessary for SAV growth and survival.

Determination of Critical Periods

Periods chosen for application of the habitat requirements are defined as critical periods, when changes in water quality have the greatest effect on long-term SAV community survival. In the tidal fresh, oligohaline, and mesohaline regions of the Bay, SAV overwinter as root stock, turions, or seeds. As such, they are generally unaffected by water quality conditions during that time. The critical period in these regions, therefore, is the above ground growing season which occurs from the spring through the fall.

In the polyhaline region, the dominant SAV species, *Zostera marina*, is characterized by a bi-modal growth pattern, with high growth in the spring and fall and low growth during the summer and winter. Decreases in plant growth among the sites were found to be directly related to reductions in water quality only during the spring and fall. Growth was limited by low water temperatures during the winter. In the summer, conditions were found to be generally similar with growth limited by high temperatures. In the polyhaline region, therefore, water quality during the spring and fall seasons is critical to long-term community survival. Water quality measurements are integrated over the spring and fall seasons to provide a measure of habitat quality.

Averaging Method

Habitat requirements for SAV growth and survival were developed based on analysis and interpretation of seasonal medians of water quality data. Median values were used to characterize the water quality conditions that SAV were exposed to over an annual growing season of April-October. These medians were calculated separately for each site and year, since the presence and condition of SAV at a site often varied from year to year. The data were not averaged spatially (among sites) or over long periods of time (across different years). The comparison of nearshore and mid-channel water quality data was also conducted using seasonal median values for all parameters.

Median values were chosen because they are more accurate estimators of the "average" or "typical" value than mean values when the data have a skewed and/or censored distribution. Many of the data sets analyzed and presented in the SAV Technical Synthesis possess one or both characteristics to some degree. Skewed distributions occurred for parameters with a few high concentration values, such as chlorophyll *a* and total suspended solids. Censored data occurred when the results were below the method detection limit and were most common for nitrogen and phosphorus parameters measured at mid-channel stations. The median is unaffected by censored values if they make up less than half of the observations. Data used in the development of the SAV habitat requirements never had more than half the observations below detection limits.

Secchi Depth/Light Attenuation Conversion

The Secchi depth measurement is a simple field measurement that has been in use for over a century. The use of a Secchi disk to estimate water column light attenuation is based on a convenient coincidence. Light that is visible to the human eye is remarkably similar in terms of the light wavelength that is available to plants for photosynthesis (photosynthetically active radiation = 400–700 nm). More recently, photoelectric light meters have been commercially available and are used extensively to measure underwater light fields. These light meters measure light as moles of quanta between 400–700 nm wavelengths. The measurement of light quanta (= photons) is relevant, since photosynthesis is a quantum process. Discrepancies in light attenuation (measured by the Secchi disk) versus light attenuation (measured by a photosynthetically active radiation light meter) are addressed through the application of a conversion calculation.

Conversion factors between Secchi depth and light attenuation coefficient (Kd) were originally developed for clear ocean waters and more recently formulated for various estuaries. Considerable discussion over the relative merits of making such conversions has occurred, both historically (e.g., Poole and Atkins 1929) and recently (e.g., Preisendorfer 1986; Megard and Berman 1989). Developing a relevant conversion factor is particularly important when utilizing historical data sets containing Secchi data (e.g., Giesen *et al.* 1990). As simple as a Secchi depth measurement appears, there are many subjective influences on making such a measurement which have been codified into 10 "laws of the Secchi disk" (Preisendorfer 1986). In spite of these subjective aspects, open ocean Secchi depth measurements are as accurate and precise as photoelectric sensors (Megard and Berman 1989).

The application of Secchi depth measurements in determining light attenuation in turbid, coastal waters has prob-

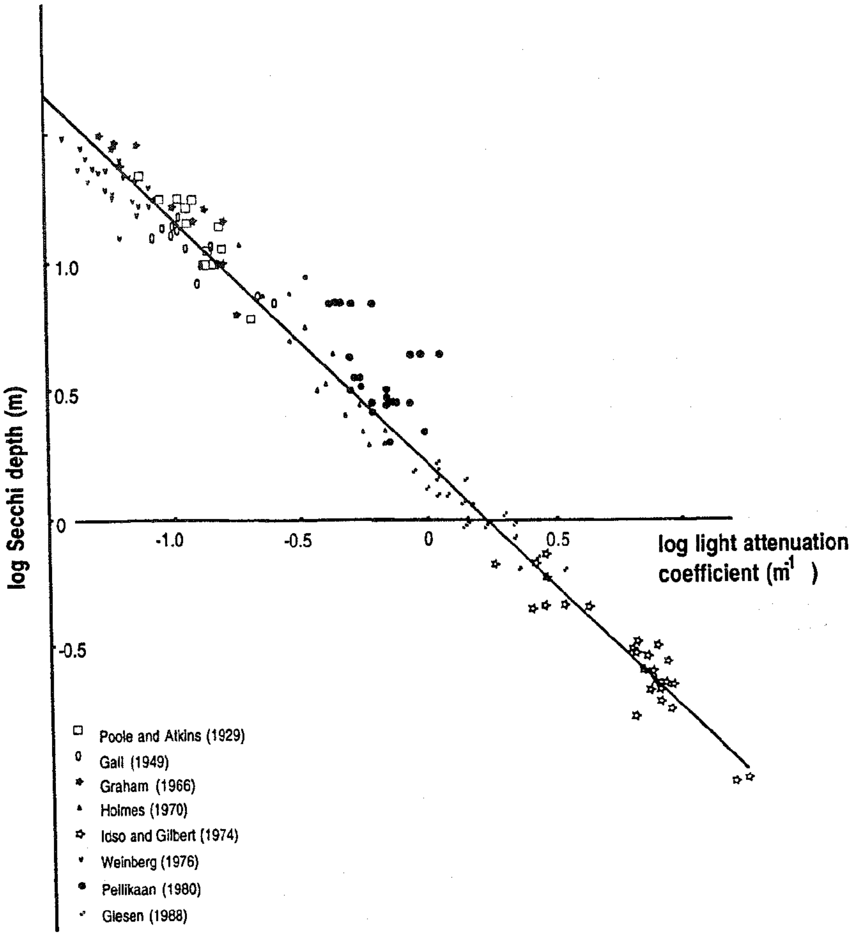


Figure III-3. Double logarithmic plot of Secchi depth and light attenuation coefficient values. Reproduced from Giesen *et al.* 1990.

lems not encountered in open ocean situations. Organic detritus from decaying plant material (e.g., salt marsh plants, SAV, and terrestrial plants) can attenuate light both as particulate matter and dissolved matter. Water in the tidal fresh and oligohaline portions of the Bay is often tea-colored from the decomposing plant matter that leaches humic substances. Because of this colored material in the water column, discrepancies between what the human eye perceives and what the photoelectric light meter measures becomes acute. Secchi depth measurements in these portions of the estuary may not be adequate estimates of light attenuation. Large adjustments in the conversion factor between Secchi depth and light attenuation coefficient are required in these regions. To develop accurate conversion factors, simultaneous measurements of Secchi depth and light attenuation must be performed for each water body.

Use of a photoelectric light meter is an easy way to avoid the problems of developing conversion factors (e.g., Preisendorfer 1986). Equally important in a turbid estuary such as Chesapeake Bay is the precise measurement of water depth that must accompany a Secchi depth measurement or light reading. Since light extinction is an exponential decay function, relatively small changes in the measurement of water depth in turbid waters led to large changes in the calculated light attenuation coefficient. Sea state, therefore, affects the accuracy of water depth measurements and requires an eleventh "law of the Secchi disk" for estuaries.

Conversion factors for various water bodies have been formulated by simultaneous Secchi depth and light attenuation measurements and is an area of considerable dispute. Even the original conversion factor of Kd = 1.7/ Secchi depth, proposed by Poole and Atkins (1929) using measurements taken in the English Channel, was recalculated by Walker (1980) to be 1.45 and by Megard and Berman (1989) to be 1.6. However, conversion factors formulated for oceanic waters are not directly applicable to Chesapeake Bay. Lower conversion factors than the Poole and Atkins value of 1.7 have been determined for turbid waters-Holmes (1970) proposed 1.44 and Walker (1980) recommended 1.46. A recent study conducted to cover the Secchi depth range of 0.5 to 2.0 m incorporated the measurements of 8 independent researchers and determined an average conversion factor of Kd = 1.65/Secchi depth (Giesen *et al.* 1990; Figure III-3).

Simultaneous measurements in the Chesapeake Bay of Secchi depth and light attenuation using a photoelectric light meter resulted in average conversion factors ranging from 1.4 to 1.7. York River data indicate a median conversion factor of 1.4 (Hayward and Webb, unpublished data). Twenty-four simultaneous measurements at the mouth of the Susquehanna River, taken in September, 1989, resulted in conversion factors ranging from 1.5 to 1.95, with an average value of 1.7 (see the upper Chesapeake Bay study area section). A conversion factor of 1.38 was determined for the Potomac River (Carter and Rybicki 1990). Separate conversion factors for the various case studies were used. For polyhaline (York River) and mesohaline (Choptank River) case studies, Kd = 1.45/Secchi depth was used. For the upper Potomac River case study, Kd = 1.38/Secchi depth was used. The upper Bay sites had conversion factors ranging from 1.5 to 1.7/Secchi depth, depending on the location.

These differences in conversion factors lead to small changes in the determination of light attenuation coefficients in turbid waters. For example, only a 5% discrepancy between light attenuation coefficient values occurs when comparing conversion factors of 1.4 versus 1.7 in water columns with a Secchi depth of 0.5 m. For the baywide application of the resultant SAV habitat requirements across salinity regimes, the conversion factor of Kd = 1.45/ Secchi depth has been adopted.

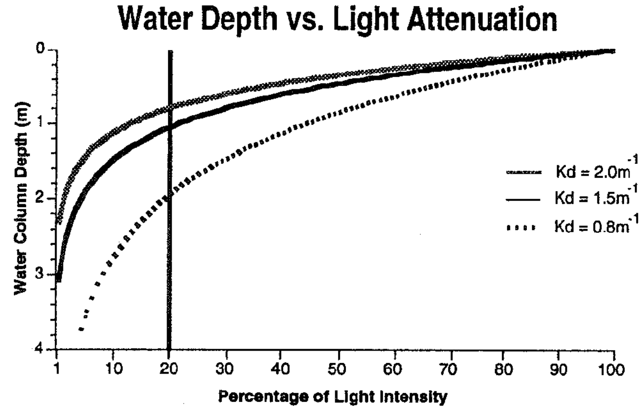


Figure III-4. The water depth versus light attenuation curves were plotted using the exponential equation $I_z=I_o{\bullet}e^{-xz}$ (see text for explanation of symbols). Changes in Kd, the light attenuation coefficient, lead to changes in the light available to SAV at different water depths. For example, if SAV survival is limited to light levels of 20% or higher of surface light intensity, then water with a Kd of $2.0m^{-1}$ will support SAV to a depth of 0.8m, water with a Kd of $1.5m^{-1}$ will support SAV to a depth of 1.1m, and water with a Kd of $0.8m^{-1}$ will support SAV to a depth of 2.0m.

Light Attenuation/SAV Depth Penetration

Minimum light requirements for SAV can be determined where the maximum depth limit and light attenuation coefficient are simultaneously measured. Percent of incident light that corresponds to maximum depth penetration of a) freshwater SAV and b) marine SAV can be determined by using the exponential light attenuation equation:

$$I_z = I_o \bullet e^{-Kd \cdot z} \qquad (1)$$

where I_z is the light at depth z, I_o is the light at the water surface, Kd is the light attenuation coefficient and z is the depth. Assuming that the minimum light requirement is the light level at the maximum depth penetration of SAV, the depth z in equation (1) can be determined by rearranging equation (1) to:

$$I_z/I_o = e^{-Kd \cdot z} \qquad (2)$$

to yield the fraction of light remaining at depth z. Multiplying the fraction I_z/I_o by 100 yields a percentage and gives the minimum light requirement as a time-integrated proportion of surface irradiance necessary to sustain SAV at its deepest habitat (Figure III-4). The conversion between Secchi depth to Kd that was used for literature values was Kd = 1.65/Secchi depth (from Giesen *et al.* 1990).

The average minimum light requirement for freshwater SAV from 88 lakes in Canada was determined to be 2.5 to 21.4% (Chambers and Kalff 1985). The minimum light requirements for marine SAV range from 2.5 to 24.4%, depending on the species (Table III-1).

The variation in minimum light requirements can be attributed to differences in physiological and morphological adaptations of the various species. Marine SAV genera, such as *Heterozostera* and *Halophila,* have low minimum light requirements and grow deeper than other SAV species where they co-exist (Shepherd and Robertson 1989; Coles *et al.* 1989, respectively), indicating that minimum light requirements vary between species. The predominant marine SAV species in Chesapeake Bay, *Z. marina*, has minimum light requirements that have been independently determined among three different locations to be about 20%. Integrated over the entire year, *Z. marina* in Chesapeake Bay has minimum light requirements of 23.9% (see the York River study area section).

In Chesapeake Bay, freshwater SAV species can grow deeper (up to 3 m) than marine SAV. This difference is attributed to the ability of some freshwater SAV species to grow to the water surface and form leaf canopies that intercept light before it is attenuated by the water column. The canopy-forming SAV (e.g., *Hydrilla verticillata, Myriophyllum spicatum*) are able to tolerate higher water column light attenuation as a consequence. Only some freshwater SAV have this morphology. Marine SAV and other freshwater SAV (e.g., *Vallisneria americana*) form meadows at the bottom of the water column (reviewed by Stevenson 1988).

The different abilities of canopy- versus meadow-forming SAV to tolerate water column light attenuation result in different minimum light requirements for these plants. For example, the minimum light requirement for canopy-forming, freshwater SAV in the tidal fresh to oligohaline sections of the Potomac River was estimated at 5% (Carter and Rybicki 1990). In contrast, estimates of meadow-

Table III-1. Maximum depth limit, light attenuation coefficient, and minimum light requirements of various species of SAV. Where Secchi depths were reported, Kd = 1.65/Secchi depth was applied (Giesen *et al.* 1990). Minimum light requirement was calculated as percent light at the maximum depth limit using 100 x $I_z/I_o = e^{-kz}$. Ranges of maximum depth limit and light attenuation coefficient values and means ± standard error of minimum light requirement are given in locations with multiple data points.

Genus **Species** (Reference)	**Location**	**Maximum Depth Limit** (m)	**Light Attenuation Coefficient** (m^{-1})	**Minimum Light Requirement** (%)
Thalassia testudinum (1)	South coast, Puerto Rico	1.0-5.0	0.35-1.50	24.4±4.2
Zostera marina (2)	Kattegat, Denmark	3.7-10.1	0.16-0.36	20.1±2.1
Zostera marina (3)	Roskilde Fjord, Denmark	2.0-5.0	0.32-0.92	19.4±1.3
Zostera marina (4)	Woods Hole, MA, U.S.A.	6.0	0.28	18.6
Syringodium filiforme (5)	Hobe Sound, FL, U.S.A.	1.9	0.93	17.2
Halodule wrightii (5)	Hobe Sound, FL, U.S.A.	1.9	0.93	17.2
Posidonia oceanica (6)	Malta, Mediterranean	35.0	0.07	9.2
Cymodocea nodosa (6)	Malta, Mediterranean	38.5	0.07	7.3
Heterozostera tasmanica (7)	Victoria, Australia	3.8-9.8	0.36-0.85	5.0±0.6
Halophila decipiens (8)	St. Croix, Caribbean	40.0	0.08	4.4
Halophila decipiens (5)	Hobe Sound, FL, U.S.A.	4.0	0.93	2.5
Halophila stipulacea (9)	Gulf of Eliat, Red Sea	50.0	0.07	3.0

References:

(1) Vicente and Rivera, 1982
(2) Ostenfeld, 1908
(3) Borum, 1983
(4) Dennison, 1987
(5) Kenworthy et al., 1990
(6) Drew, 1978
(7) Bulthuis, 1983
(8) Williams and Dennison, 1990
(9) Beer and Waisel, 1982

forming, polyhaline SAV (*Z. marina*) were on the order of 20% (Table III-1).

As a consequence of these differences in minimum light requirements, the maximum depth penetration of canopy-forming versus meadow-forming SAV are different (Figures III-5 and III-6). The ability of canopy-forming SAV to grow to the surface and have deeper maximum depth limits than meadow-forming SAV only applies in shallow, turbid estuaries like Chesapeake Bay. In clearer waters, meadow-forming SAV penetrate much deeper than canopy-forming SAV. Canopy-forming SAV are susceptible to seasonal reductions in light availability when, in the spring, young shoots which have not reached the water's surface are subject to water column light attenuation like meadow-forming SAV.

To meet the objectives of the SAV Technical Synthesis, light requirements for meadow-forming SAV have been used in the establishment of the SAV habitat requirements. Canopy-forming SAV (e.g., *H. verticillata* and *M. spicatum*) are generally limited to tidal fresh and oligohaline habitats. Meadow-forming species, like *V. americana* and *Z. marina*, inhabit larger ranges of salinities within Chesapeake Bay. Meeting light requirements for meadow-forming SAV, therefore, will ensure that the requirements are met for all Chesapeake Bay meadow-forming and canopy-forming SAV species.

Depth Penetration-Based Habitat Requirements

In presenting the SAV habitat requirements, a distinction has been made between habitat requirements that simply provide sufficient water quality to maintain existing SAV beds versus habitat requirements for restoration of SAV to deeper depths and currently non-vegetated locations. Achievement of SAV habitat requirements for one meter restoration only means that SAV will persist in the shallowest (<1 m) depths. Achievement of SAV habitat requirements for two meter restoration, in contrast, will promote a diverse SAV species composition, high biomass, and more extensive depth penetration. Habitat requirements for two meter restoration have not yet been formulated for Chesapeake Bay SAV, except for light attenuation coefficient which is described below.

Light attenuation with depth, calculated using equation (1), assuming a minimum light requirement for SAV at 20% surface irradiance (e.g., *Z. marina*), and Kd = 1.5 m^{-1} (SAV habitat requirement for one meter restoration) results in an SAV depth limit of approximately 1.1 m (Figure III-7). This indicates that to maintain SAV beds in Chesapeake Bay, a Secchi depth of at least 1.0 m is required. In contrast, the SAV habitat requirement for two meter restoration, assuming the same minimum light requirement (20% surface irradiance) and having the distribution restoration goal going down to a 2 m depth, would require that the light attenuation coefficient Kd = 0.8 m^{-1} (Figure III-8). In this case, an average Secchi depth of at least 1.8 m is required for restoration of SAV to the 2 m depth.

SAV/Habitat Feedbacks

One of the principal ecological effects of SAV beds is to modify their physical, chemical, and biological environment through various feedback controls. The consequence of these SAV/environment interactions is to create a "microenvironment" in which water quality parameters, such as those used for the SAV habitat requirements, are affected and, to some degree, controlled by SAV. For example, an existing SAV bed can baffle the water column with its leaf canopies, reducing water motion and facilitating settlement of fine particles (Ward *et al.* 1984). These particles are then bound by SAV roots and rhizomes, reducing resuspension of particles due to tidal and wind mixing (Burrell and Schubel 1977). Filter-feeding organisms associated with SAV beds also filter the water column, contributing to reduced light attenuation (Cohen *et al.* 1984). The net effect of these processes within an SAV bed is to reduce water column light attenuation, allowing existing SAV beds to persist in fluctuating conditions.

In this context, historical Chesapeake Bay SAV populations were probably not only able to modify their microenvironment but also affect water quality throughout the entire Bay. Fluctuations in water quality, buffered by this feedback control exerted by SAV, could occur without drastically affecting SAV. The resurgence of SAV in the Potomac River demonstrated the importance of these feedback controls on water quality (Carter *et al.* 1988). With the reduced SAV populations currently existing in Chesapeake Bay, however, such feedback controls are not as extensive. The habitat requirements developed and presented here are based on existing SAV populations in the Bay. Different requirements could be obtained with more abundant SAV populations, as probably was the case when the Bay was more extensively vegetated.

SAV Habitat Requirements

Empirical relationships between water quality characteristics and the presence of SAV beds have been developed using data generated in various regions of Chesapeake Bay.

Minimum Light Requirements for Canopy-Forming SAV

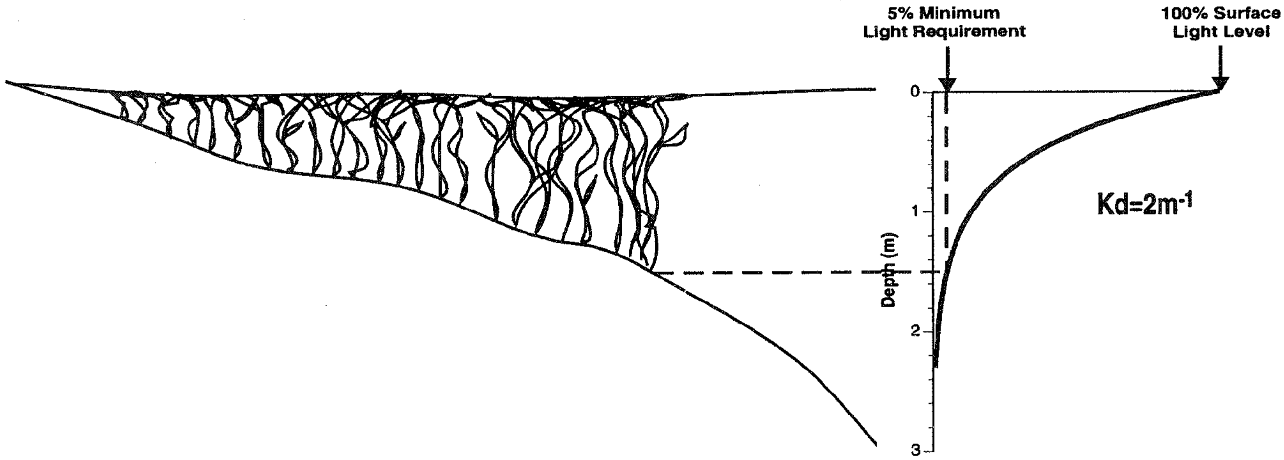


Figure III-5. The interrelationships between light attenuation, minimum light requirements for SAV, Secchi depth and maximum depth of SAV survival are depicted schematically. The intersection of the minimum light requirement of canopy forming SAV (5%) and light attenuation curve for Kd = $2m^{-1}$ determines the maximum depth of SAV survival for canopy-forming SAV as 1.5m at this light attenuation level.

Minimum Light Requirements for Meadow-Forming SAV

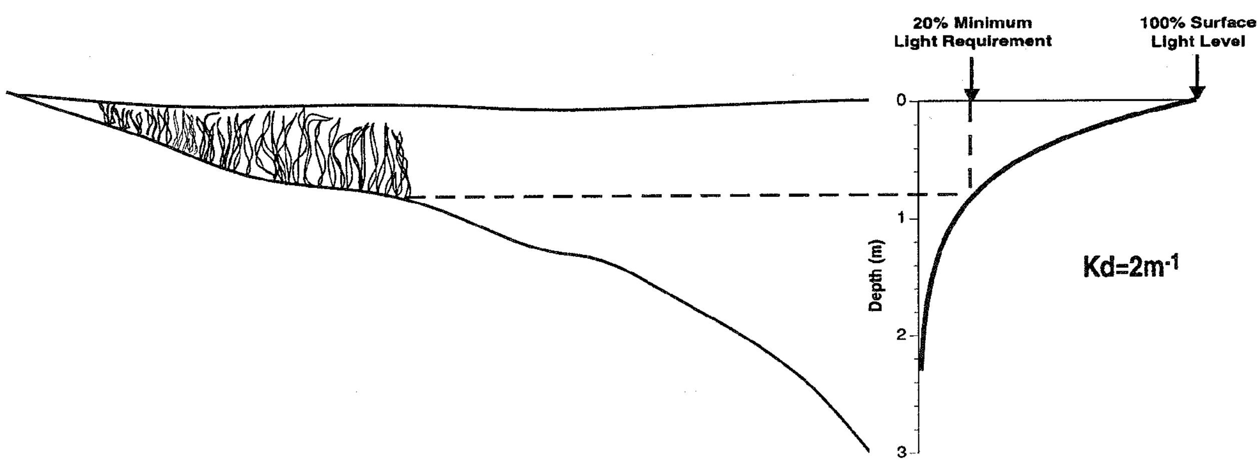


Figure III-6. The interrelationships between light attenuation, minimum light requirements for meadow-forming SAV, Secchi depth and maximum depth of SAV survival are depicted schematically. The intersection of the minimum light requirement of meadow-forming SAV (20%) and light attenuation curve for Kd = $2m^{-1}$ determines the maximum depth of SAV survival for meadow-forming SAV as 0.8m at this attenuation level.

One Meter Restoration Habitat Requirement for Light Attenuation

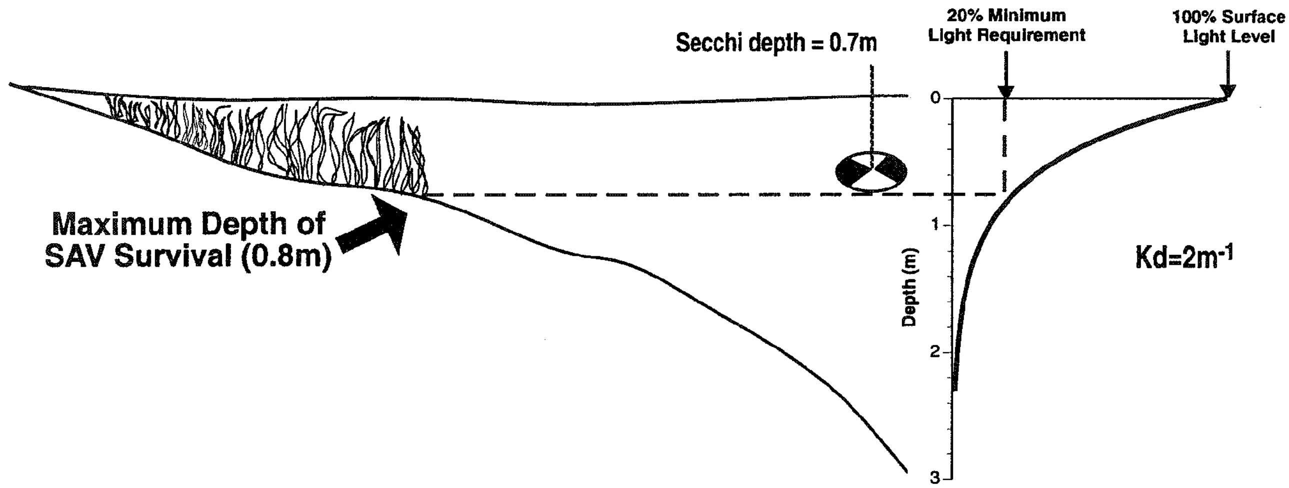


Figure III-7. The interrelationships between light attenuation, the one meter restoration habitat requirement for light attenuation (for the tidal fresh and oligohaline areas), Secchi depth and maximum depth of SAV survival are depicted schematically. The intersection of the minimum light requirement (20%) and light attenuation curve determines the maximum depth of SAV survival. Based on the achievement of a one meter restoration habitat requirement of Kd = 2.0m^{-1}, corresponding with a Secchi depth of 1.0m and given Secchi depth = 1.45/ Kd, the maximum depth of SAV survival is approximately 0.8m.

Two Meter Restoration Habitat Requirement for Light Attenuation

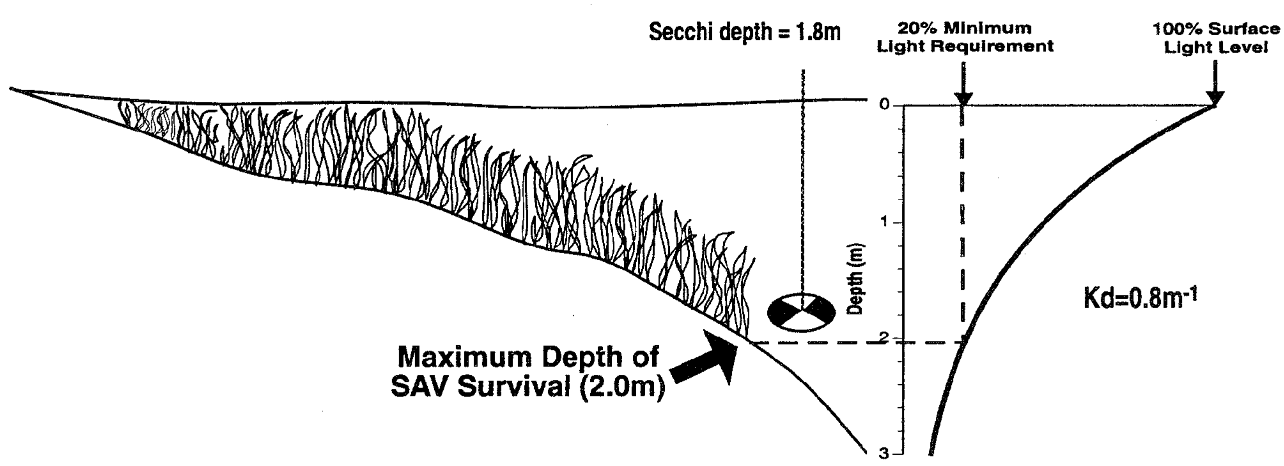


Figure III-8. The interrelationships between light attenuation, the two meter restoration habitat requirement for light attenuation, Secchi depth and maximum depth of SAV survival are depicted schematically. The intersection of the minimum light requirement (20%) and light attenuation curve determines the maximum depth of SAV survival. Based on the achievement of a two meter restoration habitat requirement of Kd = 0.8m^{-1}, corresponding with a Secchi depth of 1.8m and given Secchi depth = 1.45/Kd, the maximum depth of SAV survival is approximately 2.0m.

The four study areas were extended to five, with the upper Potomac River divided into two separate regions–tidal fresh and oligohaline. Table III-2 presents SAV habitat requirements for one meter restoration–water quality necessary to allow existing SAV to persist in the shallowest depths of its distribution (<1 m)–as developed for each of the four study areas. Achievement of these habitat requirements does not guarantee a diverse, dense, and deep-growing SAV bed. Instead, these water quality values indicate the critical point below which SAV survival is no longer possible.

The relationships of light attenuation coefficient, total suspended solids, chlorophyll *a*, dissolved inorganic nitrogen, and dissolved inorganic phosphorus with SAV survival provide an empirically derived, "real-world" solution to the problem of determining habitat requirements for SAV survival. Application of these relationships (developed from data sets collected from different river systems of Chesapeake Bay, by different investigators, and over the span of several years) forms the basis of the SAV habitat requirements presented in this document. The extensive data sets developed for the Choptank, York, and Potomac rivers, augmented by data sets from the upper Chesapeake Bay, were used to formulate habitat requirements for SAV. The span of years studied most intensively in all four study regions, 1986-1989, included hydrologically dissimilar years. The 1986-1988 years were low rainfall, low runoff years, and 1989 was a high rainfall, high runoff year.

As indicated in the conceptual model of SAV/habitat interactions, the parameters used in the delineation of habitat requirements are not independent variables. The degree of interdependence of these water quality characteristics in the mesohaline and polyhaline regions is illustrated by the three-dimensional plots of total suspended solids, chlorophyll *a*, and light attenuation coefficient for the Choptank (Figure III-9) and York rivers (Figure III-10). Sampling stations in each of the different regions were classified as having SAV beds that were either persistent or fluctuating. Areas with persistent beds were defined as areas where SAV survived across multiple growing seasons. Areas with fluctuating beds were defined as areas where SAV was present for one growing season or less or where there appeared to be significant shifts in the interannual distribution and abundance patterns. Light attenuation is strongly affected by total suspended solids and chlorophyll *a* in both regions. Analysis of these plots reveals the basis of the habitat requirements for these parameters: total suspended solids <15 mg/l, chlorophyll *a* <15 µg/l, and light attenuation coefficient <1.5 m^{-1} correspond with persistent SAV growth and survival in mesohaline and polyhaline regions. High values of total suspended solids or chlorophyll *a* increase light attenuation and, consequentially, prevent SAV from surviving. The same SAV habitat requirements for total suspended solids and chlorophyll *a* were derived for tidal fresh and oligohaline regions from the upper Chesapeake Bay and upper Potomac River study areas, although the light attenuation requirements were slightly higher (<2.0 m^{-1}).

There are few data where total suspended solids are low and chlorophyll *a* values are high, indicating a probable interaction between these water quality parameters. Periods of phytoplankton blooms (reflected in the chlorophyll *a* values) can be linked to periods of wind mixing in mesohaline and polyhaline regions where phytoplankton and nutrients are maintained in the water column by resuspension. The wind mixing events contributing to phytoplankton blooms also resuspend sediments, accounting for high total suspended solids values. In tidal fresh and oligohaline regions, phytoplankton form a significant part of the total suspended solids (Carter and Rybicki 1990).

In contrast, total suspended solids concentrations are often high when chlorophyll *a* values are low. There are several reasons for this. In mesohaline and polyhaline regions, if runoff events are not accompanied by wind mixing, high suspended solids could result. Temperature, salinity or nutrient availability could inhibit phytoplankton growth during periods when wind mixing promotes an unstratified water column otherwise conducive to phytoplankton growth. The temporal variability in high suspended solids events is probably greater than the variability in phytoplankton blooms (e.g., wind or runoff events can affect suspended solids within hours, yet phytoplankton blooms take days to develop). Regardless of the mechanism of water column light attenuation, the result is an increased light attenuation coefficient that directly affects SAV growth and survival.

The interrelationships between dissolved inorganic nitrogen, dissolved inorganic phosphorus, and light attenuation coefficient for the Choptank (Figure III-11) and York rivers (Figure III-12) reveal the basis of and interrelations between the habitat requirements for these parameters. These data indicate an interdependence of both nitrogen and phosphorus in determining light attenuation. Low concentrations of dissolved inorganic phosphorus are particularly crucial for SAV survival, with maximum growing season median values of 0.01 to 0.02 mg/l in areas with persistent SAV beds.

Limiting concentrations of dissolved inorganic phosphorus in the upper Chesapeake Bay study area were similar to those in the mesohaline and polyhaline regions. Dissolved inorganic phosphorus concentrations in the upper

Table III-2. Summary of Chesapeake Bay SAV Habitat Requirements for the Four Study Regions.

Study Region	Light Attenuation Coefficient (m^{-1})	Secchi Depth (m)	Total Suspended Solids (mg/l)
Upper Chesapeake Bay	Existing SAV beds declined at >2; <2 necessary for survival	SAV survived sheltered areas at >0.8; >1.0 necessary for unsheltered areas	No SAV found in areas >20; <10 correlated with persistent SAV beds
Upper Potomac River/Tidal Fresh	>2.4 correlated with failure of revegetation;≤2.2 correlated with revegetation	No SAV revegetation at <0.5; SAV revegetation and expansion at≥0.7	≤15-16 correlated with revegetation and expansion of SAV
Upper Potomac River/ Oligohaline	Established SAV beds survived at values as high as 2.7	SAV survived at levels as low as 0.5	≤15-16 correlated with revegetation and continued propagation
Choptank River	<1.5 correlated with persistent SAV growth; <2.0 correlated with survival of fluctuating SAV growth	>0.8	<15
York River	<1.5	>0.8	<15

Study Region	Chlorophyll *a* (µg/l)	Dissolved Inorganic Nitrogen (mg/l)	Dissolved Inorganic Phosphorus (mg/l)
Upper Chesapeake Bay	<15	—	>0.02 led to declines of fluctuating SAV beds; <0.02 necessary for SAV survival
Upper Potomac River/Tidal Fresh	≤15 supported SAV revegetation and expansion; no impact on well established beds at >30 for short time periods	See Below[1]	<0.04 correlated with revegetation of SAV
Upper Potomac River/ Oligohaline	≤15 supported SAV revegetation and expansion	See Below[2]	<0.04-0.07 correlated with survival of established SAV beds and revegetation
Choptank River	<15 SAV survived and propagated; <10 maybe necessary to sustain SAV populations	<0.15	<0.01
York River	<15	<0.15	<0.02

1. Upper Potomac River/Tidal Fresh: No dissolved inorganic nitrogen habitat requirement could be established. Concentrations of >1.5 mg/l are common. Ammonia concentrations >0.6 mg/l associated with revegetation failure. Revegetation occurred when ammonia concentration decreased to < 0.4 mg/l. Nitrate plus nitrite concentration < 1.7-2 mg/l compatible with SAV propagation and survival.

2. Upper Potomac/Oligohaline: No dissolved inorganic nitrogen habitat requirement could be established. Concentrations of >1.5 mg/l are common. SAV survived at ammonia concentrations of 0.4-0.7 mg/l. Nitrate plus nitrite concentrations <1.7-2 mg/l were compatible with SAV propagation and survival.

Note: Persistent SAV — areas where SAV survived across multiple growing seasons. Fluctuating SAV — areas where SAV was present for one growing season or less or where there appeared to be significant shifts in the interannual distribution and abundance patterns.

Total Suspended Solids, Chlorophyll *a*, and Light Attenuation: Choptank River

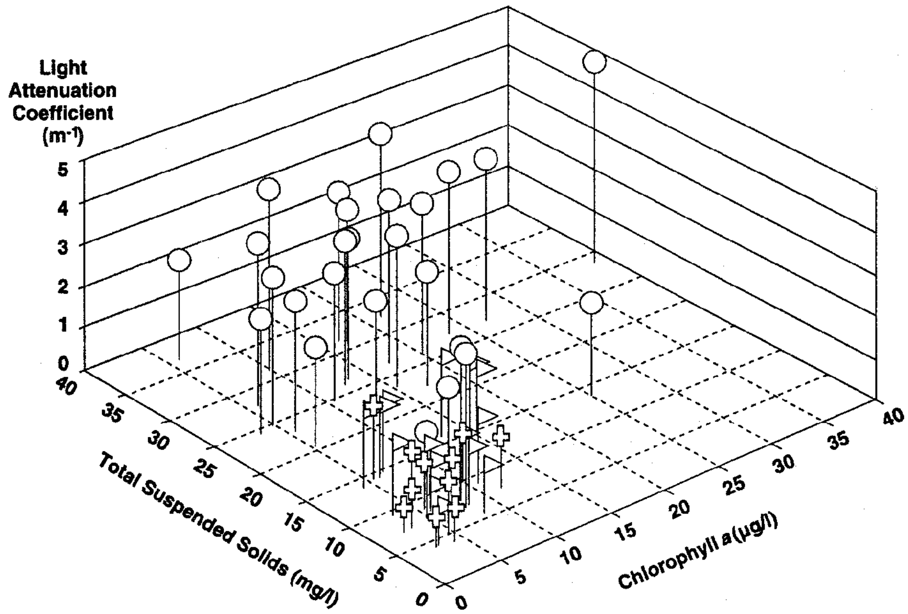


Figure III-9. Three-dimensional comparisons of May-October median light attenuation coefficient, total suspended solids, and chlorophyll *a* concentrations at the Choptank River stations from 1986-1989. Stations and years are plotted separately with SAV status indicated. Plus = persistent SAV; flag = fluctuating SAV; circle = SAV absent.

Total Suspended Solids, Chlorophyll *a*, and Light Attenuation: York River

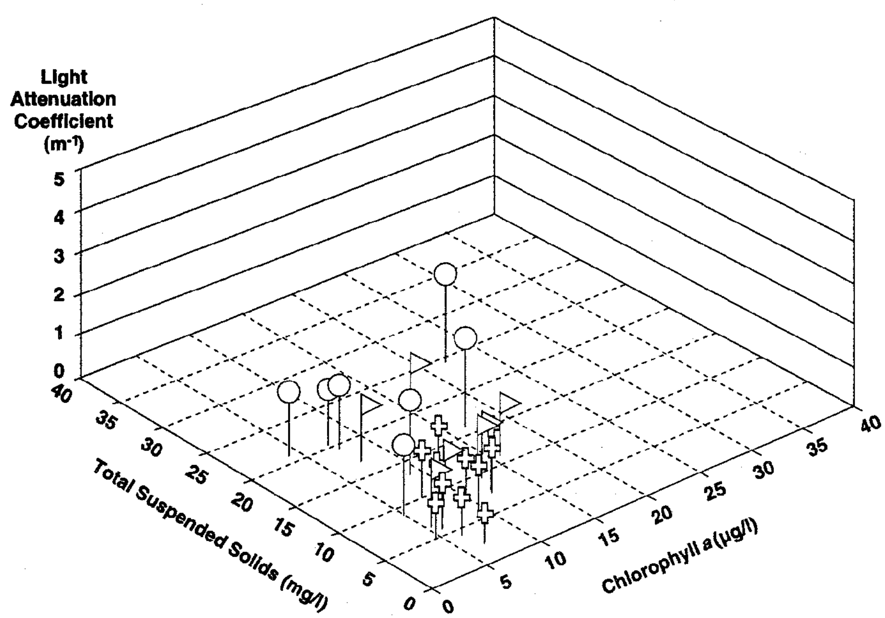


Figure III-10. Three-dimensional comparisons of combined March-May and September-November median light attenuation coefficient, total suspended solids, and chlorophyll *a* concentrations at the York River stations from 1986-1989. Stations and years are plotted separately with SAV status indicated. Plus = persistent SAV; flag = fluctuating SAV; circle = SAV absent.

Dissolved Inorganic Nitrogen, Dissolved Inorganic Phosphorus, and Light Attenuation: Choptank River

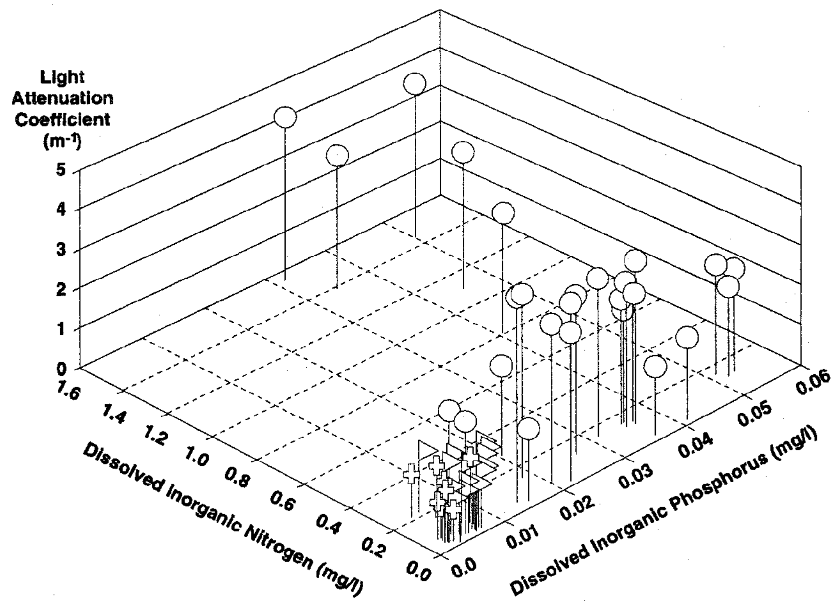


Figure III-11. Three-dimensional comparisons of May-October median light attenuation coefficient, dissolved inorganic nitrogen, and dissolved inorganic phosphorus concentrations at the Choptank River stations from 1986-1989. Stations and years are plotted separately with SAV status indicated. Plus = persistent SAV; flag = fluctuating SAV; circle = SAV absent.

Dissolved Inorganic Nitrogen, Dissolved Inorganic Phosphorus, and Light Attenuation: York River

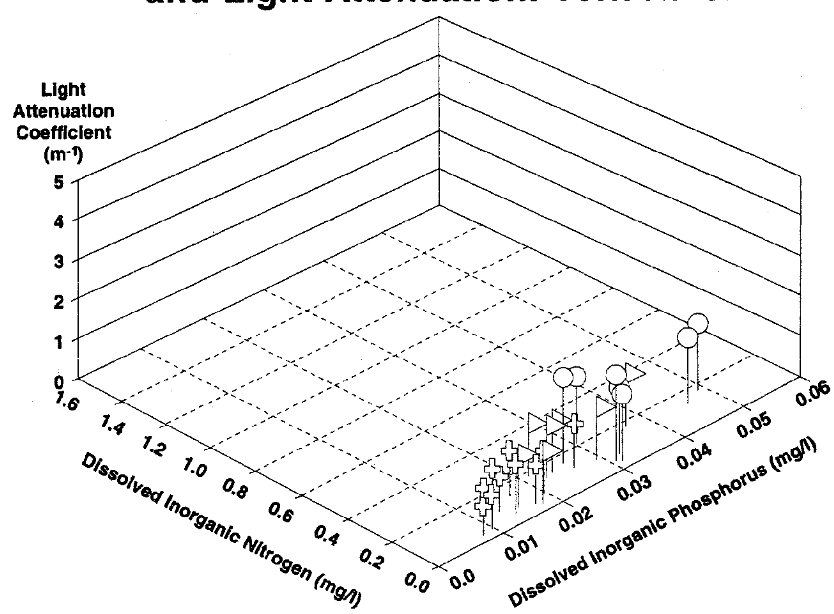


Figure III-12. Three-dimensional comparisons of combined March-May and September-November median light attenuation coefficient, dissolved inorganic nitrogen, and dissolved inorganic phosphorus concentrations at the York River stations from 1986-1989. Stations and years are plotted separately with SAV status indicated. Plus = persistent SAV; flag = fluctuating SAV; circle = SAV absent.

Potomac River study area were higher than those in the other three study areas but far lower than during the 1960s and 1970s. The potential for large phytoplankton blooms is still very high in the Potomac if climatic conditions are appropriate. Such blooms, if infrequent, may not adversely affect established SAV populations but may prevent expansion into unvegetated areas.

In contrast, dissolved inorganic nitrogen values appear less important to SAV survival, especially in tidal fresh and oligohaline regions of the Bay. These values were rarely high when phosphorus was below 0.01 mg/l, precluding an opportunity to investigate the effect of elevated nitrogen concentrations alone. Evidence from low salinity portions of the Bay indicated that high dissolved inorganic nitrogen can be tolerated by SAV (see Table III-2). In areas where dissolved inorganic nitrogen concentrations were low, SAV survival only occurred when accompanied by low phosphorus values. Dissolved inorganic nitrogen medians <0.15 mg/l correspond with persistent SAV growth in the Choptank (Figure III-11) and York rivers (Figure III-12).

Chapter IV
SAV Habitat Requirements and Restoration Targets

With the Chesapeake's wide range of salinity, the diversity of submerged aquatic vegetation (SAV) communities throughout the Bay has led to the establishment of separate habitat requirements for the following salinity regimes: tidal fresh, oligohaline, mesohaline, and polyhaline. The habitat requirements for each salinity regime are based on results from the four study areas. Each study area included at least two of the salinity regimes, so the resulting habitat requirements are not specific to results from a single study area. Tidal fresh and oligohaline SAV habitat requirements are based on upper Chesapeake Bay and upper Potomac River studies (Chapter V). Mesohaline and polyhaline SAV habitat requirements are based on Choptank River and York River studies (Chapter V).

Empirical relationships between water quality characteristics and SAV distributions provided the means of defining requirements for SAV survival. SAV habitat requirements were formulated by: a) determining SAV distributions by transplant survival and baywide distributional surveys; b) measuring water quality characteristics along large scale transects that spanned vegetated and non-vegetated regions; and, c) combining distributional data and water quality levels to establish minimum water quality conditions that support SAV survival.

This type of analysis (referred to as correspondence analysis) was strengthened by factors common to each of the case studies. Field data was collected over several years (almost a decade in the Potomac River) in varying meteo-

Table IV-1. Chesapeake Bay SAV Habitat Requirements.

	SAV Habitat Requirements For One Meter Restoration[1] — Habitat Requirements Which Effect Water Column/Leaf Surface Light Attenuation						SAV Habitat Requirements For Two Meter Restoration[1]	
Salinity[2] Regime	Light[3] Attenuation Coefficient (m-1)	Total Suspended Solids (mg/l)	Chlorophyll a (µg/l)	Dissolved Inorganic Nitrogen (mg/l)	Dissolved Inorganic Phosphorus (mg/l)	Critical Life Period	Light[3] Attenuation Coefficient (m-1)	Critical Life Period
Tidal Fresh	<2	<15	<15	—	<0.02	April-October	<0.8	April-October
Oligohaline	<2	<15	<15	—	<0.02	April-October	<0.8	April-October
Mesohaline	<1.5	<15	<15	<0.15	<0.01	April-October	<0.8	April-October
Polyhaline	<1.5	<15	<15	<0.15	<0.02	March-November	<0.8	March-November

1. The SAV habitat requirements are applied as median values over the April-October critical life period for tidal fresh, oligohaline, and mesohaline salinity regimes. For polyhaline salinity regimes, the SAV habitat requirements are applied as median values from combined March-May and September-November data. Light attenuation coefficient should be applied as the primary habitat requirement; the remaining habitat requirements should be applied to help explain regional or site specific causes of water column and leaf surface light attenuation which can be directly managed.
2. Tidal fresh=<0.5ppt; oligohaline=0.5-5ppt; mesohaline=>5-18ppt; and, polyhaline=>18ppt.
3. For determination of Secchi depth habitat requirements, apply the conversion factor Secchi depth=1.45/light attenuation coefficient.

rologic and hydrologic conditions by different investigators. SAV distributions in the four case studies across all salinity regimes were responsive to the five water quality parameters used to develop habitat requirements. In addition, inter-annual changes in water quality led to changes in SAV distribution and abundance in each region that were consistent with the habitat requirements.

SAV habitat requirements represent water quality conditions sufficient to support survival, growth, and reproduction of SAV to water depths of one meter and two meters (Table IV-1). For SAV to survive to one meter, light attenuation coefficients <2 m^{-1} for tidal fresh and oligohaline regions and <1.5 m^{-1} for mesohaline and polyhaline regions were needed. Total suspended solids (<15 mg/l) and chlorophyll *a* (<15 ug/l) values were consistent for all regions. However, one meter habitat requirements for dissolved inorganic nitrogen and dissolved inorganic phosphorus varied, as anticipated, between salinity regimes. In tidal fresh and oligohaline regions, SAV survive episodically and chronically high dissolved inorganic nitrogen concentrations, consequently habitat requirements for dissolved inorganic nitrogen were not determined for these regions. In contrast, maximum dissolved inorganic nitrogen concentrations of 0.15 mg/l were established for mesohaline and polyhaline regions. The SAV habitat requirement for dissolved inorganic phosphorus was <0.02 mg/l for all regions except for mesohaline regions (<0.01 mg/l). SAV habitat requirements for two meters were not determined by water quality correlations with SAV distributions due to lack of data; however, a habitat requirement for light attenuation coefficient (<0.8 m^{-1}) was calculated.

Overall, SAV habitat requirements developed for total suspended solids and chlorophyll *a* are identical for all salinity regimes of Chesapeake Bay. However, there is a difference between light attenuation coefficients in tidal fresh and oligohaline (<2.0 m^{-1}) and mesohaline and polyhaline (<1.5 m^{-1}) regions. This difference is partially explained by the lack of persistent SAV beds in the tidal fresh and oligohaline regions. For example, most of the SAV in the upper Chesapeake Bay goes through extensive year-to-year variation in abundance resulting from changes in precipitation and Susquehanna River runoff (Chapter V). SAV habitat requirements for the salinity regimes are, therefore, more a reflection of fluctuating rather than persistent SAV. This accounts for the less stringent light attenuation coefficient habitat requirement for tidal fresh and oligohaline regions.

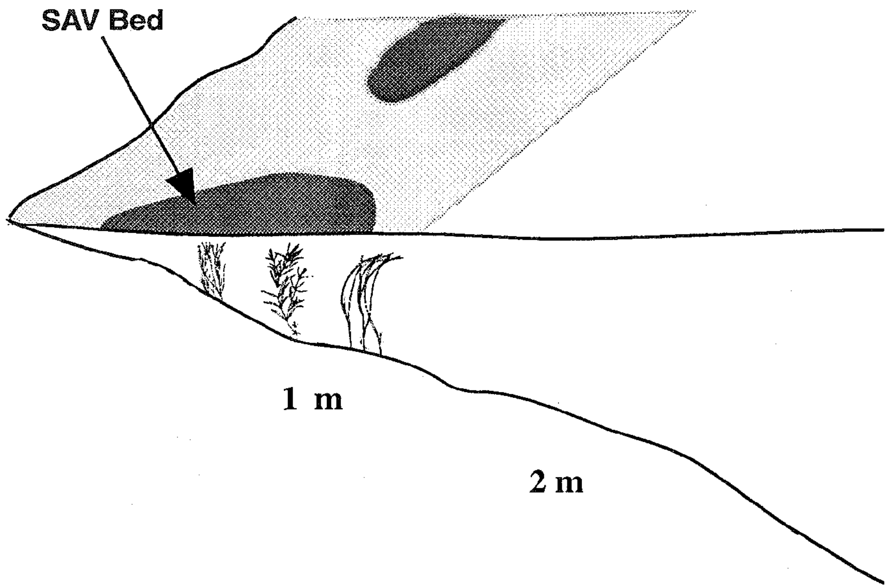
SAV habitat requirements for dissolved inorganic nitrogen and dissolved inorganic phosphorus differ substantially between salinity regimes. The lack of dissolved inorganic nitrogen habitat requirements for tidal fresh and oligohaline regions reflects the ability of SAV to survive the variable dissolved inorganic nitrogen concentrations in these regions. The importance of dissolved inorganic nitrogen in mesohaline and polyhaline regions, reflected in a habitat requirement of <0.15 mg/l, is related to the relative importance of nitrogen as a limiting nutrient for plant growth in marine habitats (e.g., Valiela 1988). In contrast, the relative importance of phosphorus as a limiting nutrient for plant growth in freshwater habitats contributes to the lower dissolved inorganic phosphorus habitat requirement for mesohaline compared to polyhaline reaches. Once again, the tidal fresh and oligohaline regions have less stringent requirements for dissolved inorganic phosphorus as a result of the presence of only fluctuating SAV beds.

SAV habitat requirements for tidal fresh and oligohaline regions of Chesapeake Bay were developed based on distributions of native, meadow-forming species. The lower tidal fresh and oligohaline reaches of the Potomac River have extensive SAV beds along its shorelines. These well established Potomac River SAV beds are able to withstand higher light attenuation coefficient and dissolved inorganic phosphorus levels, as monitored in the mid-channel, compared to other tidal fresh and oligohaline areas of Chesapeake Bay where SAV growth is absent or fluctuating. In the upper Potomac River, an exotic SAV species *(Hydrilla verticillata)* with a canopy-type architecture and a lower minimum light requirement (Figures III-5 and III-6) outcompetes native, meadow-forming SAV species. These *Hydrilla* beds are better able to baffle the water column within the bed and alter water clarity compared to meadow-forming SAV (Carter *et al.* 1988). However, species introductions of SAV typically follow a boom/bust cycle in abundance, with a rapid expansion of areal coverage followed by a diminution of abundance, as in the *Myriophyllum spicatum* introduction into Chesapeake Bay (Bayley *et al.* 1968, 1978). Hence development of habitat requirements for a recently introduced species (e.g., *Hydrilla*) would not likely be valid over a long time period.

Light attenuation, through the water column and at the leaf surface, is the principal factor influencing SAV. The light attenuation coefficient habitat requirement reflects the minimum water column light attenuation level at which SAV survive and grow. Total suspended solids and chlorophyll *a* directly influence and, therefore, can be used to explain sources of water column light attenuation. Dissolved inorganic nitrogen and dissolved inorganic phosphorus also directly affect the potential for leaf surface light attenuation through epiphytic growth. Although the

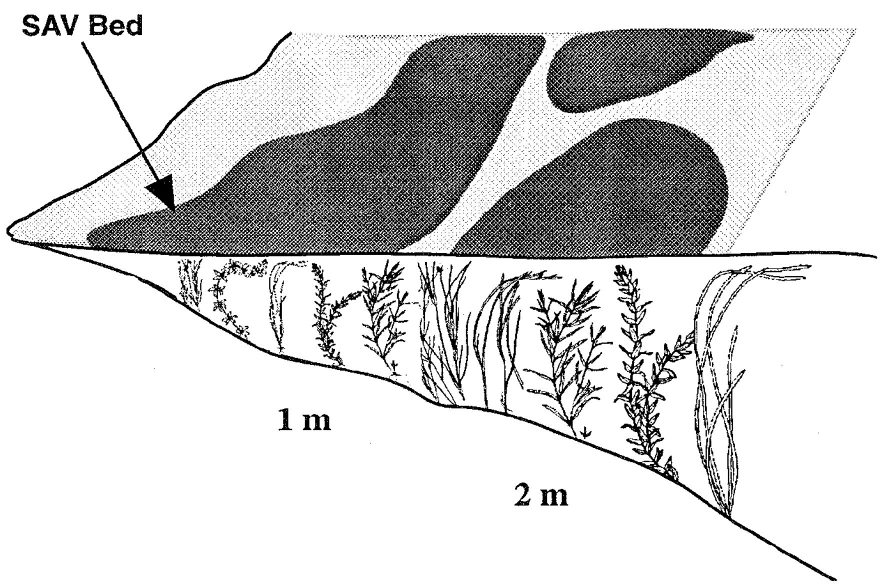
Anticipated Results with the Achievement of the Chesapeake Bay SAV Habitat Requirements

SAV Beds When Habitat Requirements for One Meter Restoration Are Achieved



- **Provides minimum water quality necessary to support existing SAV beds.**
- **New growth limited as light attenuation requirement provides sufficient light penetration for SAV growth down to only 1 m depth.**
- **SAV beds characterized by low biomass, low density, and limited species diversity.**

SAV Beds When Habitat Requirements for Two Meter Restoration Are Achieved



- **Provides water quality necessary for achievement of SAV distribution, density, and species diversity goals.**
- **Light attenuation requirement provides sufficient light penetration for SAV growth down to 2 m depth.**
- **SAV beds characterized by maximum density, high biomass, and native/diverse species.**

Figure IV-1. Anticipated composition and areal coverage of SAV beds given achievement of the one meter (top figure) and two meter (bottom figure) habitat requirements. SAV beds where the one meter habitat requirements are hypothetically achieved would have patchy to continuous areal coverage (shaded area on the water surface). In contrast, the SAV beds where the two meter habitat requirements are hypothetically achieved would have more continuous areal coverage with higher biomass, density and species diversity than the SAV beds where only the one meter habitat requirements were achieved.

light attenuation coefficient habitat requirement should be applied as the primary SAV habitat requirement, application of the remaining SAV habitat requirements will help explain regional or site specific causes of water column and leaf surface light attenuation which can be directly managed through nutrient reductions and shoreline erosion controls.

Achievement of the SAV habitat requirements for one meter restoration will provide water quality conditions sufficient to support continued survival of existing SAV beds (Figure IV-1). They would also provide for expansion of existing beds and establishment of new SAV beds down to a water column depth of approximately one meter.

Achievement of the SAV habitat requirements for two meter restoration would provide water quality conditions suitable for SAV survival, growth, reproduction, expansion of existing beds, and reestablishment of new beds down to approximately the two meter depth contour in areas defined as existing or potential SAV habitat under the SAV distribution restoration targets (Figure IV-1). In contrast to the habitat requirements for one meter restoration, achievement of the two meter restoration habitat requirement would promote a more diverse SAV species composition, higher biomass, and more extensive depth penetration.

The SAV light attenuation habitat requirement for two meter restoration (Table IV-1) was derived using an exponential light attenuation equation which quantitatively defines the interrelationship between light attenuation, minimum light requirements and depth penetration of SAV (see Chapter III). The SAV light attenuation habitat requirement for two meter restoration was determined to be Kd $<0.8\ m^{-1}$, based on 20% surface irradiance as the minimum light requirement.

Concentrations of total suspended solids, chlorophyll *a*, dissolved inorganic nitrogen, and dissolved inorganic phosphorus required to attain the light attenuation conditions defined in the habitat requirements for two meter restoration could not be determined through analysis of the findings from the four study areas. Existing habitat conditions in the study areas (with the possible exception of some areas in the upper Potomac River) and, in general, throughout Chesapeake Bay only support SAV growth down to the one meter depth. Further field studies are necessary in areas where there is persistent SAV growth down to two meters to complete the development of SAV habitat requirements for two meter restoration. These habitat requirements will be developed through quantitative correspondences and extrapolation between concentrations of these parameters, light attenuation and SAV regrowth, and depth penetration down to two meters.

Baywide Application of SAV Habitat Requirements

Correlations between SAV habitat requirements

The five water quality parameters used for SAV habitat requirements were chosen based on the conceptual model of SAV/habitat interactions (Figure II-11) since all are known to affect SAV growth and survival. Empirical studies summarized in Chapter V show that with the exception of dissolved inorganic nitrogen in tidal fresh and oligohaline regimes, all five parameters affected SAV growth. However, before their applicability in other areas was tested, the degree of their correlations with each other was examined since all of the five habitat requirements affect light availability. This examination showed that the correlations were not as high as might be expected and that all five habitat requirements should be applied together.

Because they all affect light availability, the five habitat requirements would be expected to show positive correlations with each other–when one is high, the others would tend to be high, and vice versa. This tendency is evident for some parameters in the three-dimensional plots based on the Choptank and York river study area monitoring data (Figures III-9 to III-12). However, this positive correlation is not universal, and the strength of the association varies markedly among different pairs of parameters and in different areas. Also, one element of light attenuation, caused at the leaf surface by epiphytes (Figure II-11), is not measured directly by monitoring programs, although it should be positively correlated with nutrient levels.

Correlations between parameters are shown from Choptank River nearshore monitoring data, using May-October annual medians of 1986-1989 data from stations with SAV (Table IV-2), and stations with no SAV (Table IV-3). Data from the two groups of stations were not combined due to the different magnitudes and directions of correlations found, which can produce spurious correlations when data are combined. The only statistically significant ($p < 0.05$) positive correlations found in both tables were between light attenuation coefficient and total suspended solids and between light attenuation coefficient and chlorophyll *a*. Total suspended solids and chlorophyll *a*, and light attenuation and dissolved inorganic phosphorus, were also significantly correlated at stations with SAV (Table IV-2). Since both total suspended solids and chlorophyll *a* affect light attenuation, and total suspended solids includes chlo-

TABLE IV-2. Correlations between SAV habitat requirements for stations with SAV, Choptank River nearshore stations, May-October annual medians, 1986-1989. Sample size was 30 observations for light attenuation coefficient (Kd), total suspended solids (TSS), chlorophyll *a* (CHLA), dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphorus (DIP). Open boxes placed around statistically significant ($p<0.05$) positive correlations.

KEY: Pearson's r (p value)

	TSS	CHLA	DIN	DIP
KD	$\boxed{0.756\ (0.0001)}$	$\boxed{0.541\ (0.002)}$	-0.099 (0.602)	$\boxed{0.383\ (0.037)}$
TSS		$\boxed{0.499\ (0.005)}$	-0.147 (0.438)	0.227 (0.227)
CHLA			0.199 (0.291)	0.261 (0.163)
DIN				0.245 (0.191)

TABLE IV-3. Correlations between SAV habitat requirements for stations with no SAV, Choptank River nearshore stations, May-October annual medians, 1986-1989. Sample size was 26 observations for light attenuation coefficient (Kd), total suspended solids (TSS), chlorophyll *a* (CHLA), dissolved inorganic nitrogen (DIN), and dissolved inorganic phosphorus (DIP). Open boxes placed around statistically significant ($p<0.05$) positive correlations.

KEY: Pearson's r (p value)

	TSS	CHLA	DIN	DIP
KD	$\boxed{0.743\ (0.0001)}$	$\boxed{0.475\ (0.014)}$	0.294 (0.145)	-0.0960 (0.641)
TSS		0.133 (0.516)	0.222 (0.277)	-0.135 (0.510)
CHLA			-0.0763 (0.711)	-0.221 (0.278)
DIN				0.299 (0.139)

rophyll *a*, the correlations among light attenuation, total suspended solids, and chlorophyll *a* were expected. The correlation between light attenuation and dissolved inorganic phosphorus was barely significant ($p = 0.037$). The correlation between light attenuation and dissolved inorganic phosphorus was the only significant correlation between any of the two light-related parameters and the two nutrient parameters. These lower correlations were expected, as the three light-related parameters all involve particulates and the nutrients are from filtered samples. Correlations between these parameters in York River nearshore data are generally similar but smaller, probably due to the smaller number of stations in the York (6 per year compared to 14 in the Choptank).

The correlations in Tables IV-2 and IV-3 support the application of all five habitat requirements. Even for the light attenuation coefficient, total suspended solids, and chlorophyll *a* habitat requirements, the magnitudes of their correlations are low enough to demonstrate that they all separately account for components of the total light availability. The highest correlations, between light attenuation and total suspended solids, show that one variable can explain only 55-57% of the variance in the other. The need to apply all five habitat requirements is also illustrated by specific monitoring sites and years that had only two habitat requirements exceeded (based on growing season medians) and had no SAV. These sites and years include:

- Warwick Creek in the Choptank River, 1986-1988, where the dissolved inorganic phosphorus habitat requirement was exceeded (0.014-0.04 mg/l), and light attenuation coefficient habitat requirement was exceeded (1.7-2.1 m^{-1}), but all other habitat requirements were met;

- Dickinson Bay in the Choptank River, 1989, where the dissolved inorganic nitrogen habitat requirement was exceeded (0.22 mg/l), and light attenuation coefficient was exceeded (2.1 m^{-1}), but all other habitat requirements were met;

- Catlett Island in the York River, 1986, where the dissolved inorganic phosphorus habitat requirement was exceeded (0.05 mg/l), and light attenuation coefficient habitat requirement was slightly exceeded (1.7 m^{-1}), but all other habitat requirements were met; and,

- Catlett Island and Claybank in the York River, 1987, where the dissolved inorganic phosphorus habitat requirement was exceeded (0.03 mg/l), and total suspended solids habitat requirements was exceeded (22-23 mg/l), but all other requirements were met.

The last two examples also show that although water column light attenuation is conceptually the most important of the five habitat requirements, some sites without SAV met the later column-based light attenuation coefficient habitat requirement.

In summary, there are several reasons why all five SAV habitat requirements need to be applied together:

1. All five parameters are known to affect SAV growth and survival via the pathways identified in the SAV/habitat interactions conceptual model (Figure II-11);

2. All of the correlations between the habitat requirements vary in magnitude, and some pairs of parameters show few or no statistically significant correlations;

3. The correlations between the habitat requirements were low enough to demonstrate that application of all five parameters is required to account for all the factors reducing light availability at the leaf surface; and,

4. Case studies show that SAV growth may be prevented when as few as two habitat requirements are not met, and that the two parameters involved vary over space and time.

Habitat Requirements Application

The habitat requirements for SAV by salinity regime are based on monitoring and research findings from four study areas. These study areas cover the full range of salinity from tidal fresh to polyhaline conditions. As the SAV species within the four study regions are also found throughout the Chesapeake Bay and its tributaries (within similar salinity conditions), the habitat requirements for each study area should apply baywide for areas of similar salinity.

Table IV-4. Process for validation of the baywide application of the SAV habitat requirements.

- Identification of the subset of stations that characterized existing or potential SAV habitat from all Chesapeake Bay mainstem and tidal tributary water quality monitoring stations;

- Assignment of a set of SAV habitat requirements for one meter restoration to each station based on the April-October mean salinity at the station for that year;

- Calculation of the April-October (for tidal fresh, oligohaline and mesohaline stations) or combined March-May and September-November (for polyhaline stations) median values for surface only light attenuation coefficient, total suspended solids, chlorophyll *a*, dissolved inorganic nitrogen and dissolved inorganic phosphorus data for each station using 1987 and 1989 data separately;

- Documentation of the presence or absence of SAV in proximity to each station for each of the two years based on 1987 and 1989 aerial survey data;

- Comparison of the median values for the five water quality parameters for each year with the corresponding set of salinity based SAV habitat requirement for one meter restoration; and,

- Documentation of whether the median water quality values met the corresponding SAV habitat requirements with a ratio of the number of SAV habitat requirements met compared to the total number of SAV habitat requirements for which data were available.

Baywide applicability of the SAV habitat requirements for one meter restoration was tested using water quality monitoring data and corresponding SAV aerial survey distribution data for 1987 and 1989 (Table IV-4). Based on the findings from comparative analysis of mid-channel and nearshore water quality data (see Chapter VII), data from mid-channel tributary and lateral mainstem water quality monitoring stations were used to characterize nearshore habitat conditions. If the station was not close enough to existing or potential SAV habitat to characterize water quality for SAV, it was excluded from the analysis.

The analysis was based on data from 105 stations per year that characterized water quality in existing or potential SAV habitats. Tidal fresh and oligohaline stations in the Potomac River were excluded from the analysis due to the presence of the exotic canopy-forming SAV, *H. verticillata*, which has different habitat requirements.

Because there were some statistically significant correlations between habitat requirements, applicability was first examined for each parameter separately to see if they varied in their ability to predict SAV presence or absence. If a parameter was a perfect predictor of SAV presence or absence, the percentage of stations with the habitat requirement met would be 100% when SAV was present, and 0% when SAV was absent, respectively. Since this analysis showed that none of the parameters were consistently better predictors of SAV presence than the others, the number of requirements met per station per year was also calculated. If the five habitat requirements applied as a group were good predictors of SAV presence or absence, most of the stations with SAV would have four or five habitat requirements met, and most of the stations without SAV would have three or fewer of the habitat requirements met. This analysis was first done for mid-channel stations in three study areas (upper Chesapeake Bay, Choptank

Table IV-5. Application of the five SAV habitat requirements to growing season medians of data from mid-channel monitoring stations from 1987 (A) and 1989 (B). Percentages represent the frequency of stations in that category that had the habitat requirement met, followed by the total number of stations in that category in parentheses. Numbers of stations vary slightly due to missing data. Light attenuation coefficient (Kd), total suspended solids (TSS), chlorophyll *a* (CHLA), dissolved inorganic nitrogen (DIN), dissolved inorganic phosphorus (DIP).

A. 1987 Mid-channel stations

Salinity Regime	SAV Present	Habitat Requirement KD	TSS	CHLA	DIN	DIP
Tidal	Yes	100% (1)	100% (1)	100% (1)	–	100% (1)
Fresh	No	25% (4)	(0)	50% (6)	–	40% (5)
Oligo-	Yes	0% (2)	50% (2)	50% (2)	–	50% (2)
haline	No	20% (18)	27% (15)	48% (21)	–	57% (21)
Meso-	Yes	84% (19)	88% (17)	100% (19)	79% (19)	89% (19)
haline	No	45% (42)	65% (41)	81% (42)	33% (42)	57% (42)
Poly-	Yes	100% (11)	100% (10)	82% (11)	100% (11)	100% (11)
haline	No	33% (3)	100% (1)	67% (3)	67% (3)	100% (3)

B. 1989 Mid-channel stations

Salinity Regime	SAV Present	Habitat Requirement KD	TSS	CHLA	DIN	DIP
Tidal	Yes	100% (1)	100% (1)	100% (1)	–	100% (1)
Fresh	No	17% (4)	43% (7)	43% (7)	–	0% (7)
Oligo-	Yes	0% (1)	0% (1)	100% (1)	–	100% (1)
haline	No	5% (19)	14% (21)	57% (21)	–	67% (21)
Meso-	Yes	95% (19)	79% (19)	100% (19)	68% (19)	95% (19)
haline	No	38% (42)	40% (42)	79% (42)	21% (42)	60% (42)
Poly-	Yes	100% (11)	55% (11)	100% (11)	100% (11)	100% (11)
haline	No	33% (3)	33% (3)	100% (3)	67% (3)	100% (3)

Table IV-6. Number of SAV habitat requirements achieved for stations, with and without SAV, based on growing season medians of data from mid-channel monitoring stations from 1987 and 1989. Percentages represent the frequency of stations in that category which had the indicated number of habitat requirements achieved.

Year	SAV Present	Number of Habitat Requirements Achieved 5	4	3	2	1	0	No. of Stations
1987	Yes	53%	29%	12%	3%	3%	0%	34
	No	9%	13%	17%	24%	28%	10%	71
1989	Yes	38%	44%	16%	0%	3%	0%	32
	No	1%	15%	16%	26%	34%	7%	73

River, and York River) and compared to results from other mid-channel stations outside the study areas. Because results for the two groups of stations were very similar, combined results for all stations that characterized SAV habitats are presented here.

Results

The growing season median water quality number of habitat requirements met and SAV presence or absence is shown for all of the Chesapeake Bay Program mainstem and tributary monitoring stations in Appendix A, Tables A-1 (1987) and A-2 (1989). These results were summarized by salinity regime, SAV presence parameter, and number of habitat requirements met in the following analyses.

The percentage of stations per year that had each of the five habitat requirements met were tabulated in each salinity regime by SAV presence (Table IV-5). No single habitat requirement was a perfect predictor of SAV presence or absence, and no single habitat requirement was consistently a better predictor than others. Differences among salinity regimes appear more pronounced than differences among habitat requirements. Water quality was generally better at polyhaline stations than at other stations, resulting in high percentages of habitat requirements met at polyhaline stations.

Because the preceding analysis did not show any marked differences among the five habitat requirements, they were also tabulated according to how many requirements were met per year. Tabulations were made for each salinity regime. Combined results for all four regimes are shown (Table IV-6) because the sample sizes were small in tidal fresh and oligohaline regimes, and the results from the four regimes were similar. The results show that 82% of the stations with SAV had four or five habitat requirements met each year, and 79-83% of the stations without SAV had three or fewer habitat requirements met each year. These high percentages support the application of the five SAV habitat requirements baywide, using growing season medians calculated from mid-channel monitoring data.

Summary and Conclusions

Based on these analyses using two different years of water quality conditions and SAV distribution, the Chesapeake Bay SAV habitat requirements for one meter restoration developed for tidal fresh, oligohaline, mesohaline and polyhaline habitats can be applied baywide within comparable salinity regimes using mid-channel water quality data. When the SAV habitat requirements are met, SAV is usually present in the area of improved water quality.

Chesapeake Bay SAV Restoration Targets

Distribution Restoration Targets

Historical records of SAV distribution and density in Chesapeake Bay, both quantitative (seed record, distribution surveys, etc.) and anecdotal (watermen's and citizen's observations) indicate that SAV was significantly more abundant in the past (Stevenson and Confer 1978; Carter *et al.* 1983; Orth and Moore 1984; Brush and Hilgartner 1989). Although the actual distribution has never been quantified, estimates of historical SAV distribution range upwards of 100,000 hectares or more baywide. The most recent aerial survey (1990) indicated that 24,296 hectares of the Bay's bottom has SAV (Orth *et al.* 1991).

Table IV-7. Chesapeake Bay SAV distribution restoration targets and 1990 SAV distribution.

1990	SAV Distribution Restoration Targets[1]		
SAV Distribution	Tier I Target	Tier II Target[2]	Tier III Target
24,393	46,025 (53%)	In Process	247,658 (10%)

1. The percentage in parenthesis beside each target is the 1990 SAV distribution as a percentage of that SAV distribution restoration target. All SAV distributions are in hectares.
2. Efforts to quantify areas covered under the Tier II Target were in process at the time of publication.

Currently, most SAV is found in water depths of 1.0-1.5m or less at mean low water (MLW). In the past, it is likely that significant stands of SAV grew to depths of three meters or more. This reasoning is based on the knowledge that species growing in the Bay have been documented at these deeper depths in other regions where light penetration is much greater than currently found in the Bay (Table III-1, Duarte 1991). In addition, there are some areas where the meadow-forming SAV species, *Zostera marina*, grows to depths of two meters MLW (Orth, personal observation), and a canopy-forming species *(H. verticillata)* grows to depths of three meters in the Potomac River. Examination of aerial photography from the 1960s indicates that *Z. marina* may have penetrated to water depths greater than two meters in Chesapeake Bay. As noted earlier, deteriorating water quality due to increased inputs of nutrients and sediments has resulted in less light penetration, which in turn reduces maximum depth penetration of SAV. Alternatively, improvements in water quality should result in increased distribution and density of SAV if sufficient propagules are present and other environmental factors limiting growth (e.g., salinity, temperature) are within the tolerance limits of the species.

In defining habitat requirements for SAV, management agencies have been given the necessary scientific information to set specific water quality goals. Achievement of these habitat requirements will result in continued growth of existing SAV as well as restoration of potential habitat that is presently unable to support SAV.

To assess the success of Bay restoration strategies implemented by management agencies there must be a yardstick to measure the effectiveness of each strategy. The most appropriate method would be to measure the net gain of the particular resource in question. "The Submerged Aquatic Vegetation Policy for the Chesapeake Bay and Tidal Tributaries" (Chesapeake Executive Council 1989) has set a goal to achieve a net gain in SAV distribution and density and committed the Chesapeake Bay Program agencies to set "regional SAV restoration goals considering historical distribution records and estimates of potential habitat." This net resource gain is intimately tied to the baywide and tributary specific nutrient reduction strategy for Chesapeake Bay.

To provide management agencies with stepwise measures of progress, a tiered set of SAV distribution restoration targets have been established for Chesapeake Bay (Table IV-7). Each target represents expansions in SAV distribution anticipated in response to improvements in water quality over time, measured as achievement of the SAV habitat requirements for one meter restoration and the SAV habitat requirements for two meter restoration.

The distribution restoration targets were developed by mapping potential SAV habitat on USGS quadrangles and comparing these areas with the historical survey data and more recent distribution data (Orth *et al.* 1991) through a process described in Chapter VI. In summary, potential habitat was initially defined as all shoal areas of Chesapeake Bay less than two meters. Although historical SAV in Chesapeake Bay may have grown in depths of up to three meters, the two meter depth contour was chosen because it was the best compromise of the anticipated maximum depth penetration of most SAV species when both sets of habitat requirements are achieved baywide and observations from current depth distributions of SAV. Selected areas were excluded as being highly unlikely to support SAV (even if water quality was significantly improved) based on long-term, historical observations and recent survey information.

Tier I Target: *Restoration of SAV to areas currently or previously inhabited by SAV as mapped through regional and baywide aerial surveys from 1971 through 1990.*

Achievement of this SAV distribution restoration target depends on achievement of the SAV habitat requirements for one meter restoration (Table IV-1) in areas delineated as current or previous SAV habitat and on the presence of sufficient propagules and other environmental factors that limit growth (e.g., salinity, temperature, sediment substrates, herbicides) remaining within the tolerance limits of the SAV species.

A total of 46,025 hectares of SAV has been mapped as past and present habitat compromising the Tier I target. The 1990 estimate of SAV abundance indicates that current levels of SAV are 53% of Tier I. Areas with greater than 50% of the Tier I target are CB1–57% (Northern Chesapeake Bay), CB5–79% (Lower Chesapeake Bay), CB6–65% (Western Lower Chesapeake Bay), CB7–67% (Eastern Lower Chesapeake Bay), TF2–53% (Upper Potomac River), RET2–74% (Middle Potomac River), ET2–78% (Elk/Bohemia River), WE4–71% (Mobjack Bay), and EE3–76% (Tangier Sound). Although the two upper Bay segments that include the Susquehanna Flats region have high percentages, 95% of the vegetated area is very sparse and has remained sparse during the aerial surveys. These segments historically supported some of the densest stands of SAV in the Bay. Today, the large area of the Flats supports only sporadic patches of one species (*M. spicatum*), whereas in the past, dense, continuous, multi-species beds were present (Bayley *et al.* 1978). Thus, the density and species diversity targets for this region are below the expected targets. Surprisingly, a large number of species are found in the many fringing beds in this region but most are dominated by one or a few species (Orth and Nowak 1990; Orth *et al.* 1991).

The rapid expansion of *H. verticillata* in the upper Potomac River in the 1980s has contributed to a relatively large area now vegetated. Although *H. verticillata* is the numerically dominant species in the Potomac, many of the areas inshore of *H. verticillata* are vegetated with numerous other SAV species (Orth and Nowak 1990; Orth *et al.* 1991).

SAV, based on the Tier I target, is doing best in the lower mainstem segments (CB5, CB6, CB7, and EE1), where water quality is expected to be better than upper Bay or upper tributary areas. In particular, SAV is notably absent or in very reduced abundance in many of the upper western shore tributaries (WT1–Bush River; WT2–Gunpowder River; WT3–Middle River; WT4–Back River; WT5–Potapsco River; WT6–Magothy River; WT7–Severn River; and WT8–South/West/Rhodes rivers), many of the Eastern Shore's tributaries (ET1–Northeast River; ET4–Chester River; ET5–Choptank River; ET6–Nanticoke River; ET7–Wicomico River; and ET10–Pocomoke River), the Patuxent River (TF1, RET1, and LE1), the lower Potomac River (LE2), the middle and upper York River (RET4, TF4), and the James River (LE5, RET5, and TF5). Of the five major western shore tributaries, the James and Patuxent rivers have the least amount of SAV.

Tier II Target: *Restoration of SAV to all shallow water areas delineated as existing or potential SAV habitat down to the one meter depth contour.*

Achievement of this SAV distribution restoration target also depends on achievement of the SAV habitat requirements for one meter restoration (Table IV-1) and aims for SAV growth down to a one meter depth. Tier II includes all areas in Tier I, as well as areas delineated within the one meter depth contour in Chesapeake Bay and its tidal tributaries. Tier II excludes a number of areas that were considered highly unlikely to support SAV. These areas occur in regions were the physical exposure to intense wave and current energy would prevent the establishment of any SAV propagules. These areas are predominantly in the mainstem of Chesapeake Bay (e.g., the shoreline between the mouth of the Potomac and Patuxent rivers). It also excludes areas where extensive physical disruption of the shoreline and nearshore habitat would prevent SAV from re-establishing (e.g., certain areas in the Hampton Roads and Baltimore Harbor regions). Achievement of this SAV distribution restoration target will also depend on the presence of sufficient propagules. In addition, other environmental factors limiting growth and reproduction (e.g., salinity, temperature, sediment substrate, and herbicides) must be within the general tolerance limits of the SAV species.

Tier III Target: *Restoration of SAV to all shallow water areas delineated as existing or potential SAV habitat down to the two meter depth.*

Achievement of this SAV distribution target depends on achievement of the SAV habitat requirements for two meter restoration for light penetration (Table IV-1) and aims for SAV growth down to two meters in depth. Tier III includes all areas in Tiers I and II as well as areas delineated within the two meter depth contour in the Chesapeake Bay and its tidal tributaries. Tier III excludes the same areas as Tier II as well as some selected areas within the one-two meter depth contour where primarily wave exposure would limit SAV growth to the one meter depth contour. Achievement of this SAV distribution restoration target will also depend on the presence of sufficient propagules. In addition, other environmental factors limiting growth and reproduction (e.g., salinity, sediment substrate, and herbicides) must be within the general tolerance limits of the SAV species.

The Tier III target shows 247,659 hectares of potential habitat within the two meter depth contour. The 1990 SAV distribution indicates that the current levels of SAV are only 10% of the target for Tier III. Areas with greater than 10% of the target are CB1–25% (Northern Chesapeake Bay), CB5–33% (Lower Chesapeake Bay), CB6–18% (Western Lower Chesapeake Bay), CB7–26% (Eastern Lower Chesapeake Bay), TF2–20% (Upper Potomac River), RET2–18% (Middle Potomac River), ET2–12% (Elk/ Bohemia River), WE4–34% (Mobjack Bay), and EE3–14% (Tangier Sound). As with the Tier I target, The greatest proportion of the highest percentage of achievement of the Tier III was in the lower Bay segments where water quality conditions are better.

Attainment of the Tier I, II, and III Chesapeake Bay SAV distribution restoration targets will ultimately rest, most importantly, on the achievement of the habitat requirements for one and two meter restoration. Once the requirements are met and maintained, SAV plants or propagules must be present to insure that a given area will rebound with SAV. A specific timeline for achieving these targets will depend on how rapidly water quality improves through the implementation of loading reduction measures for both point and nonpoint sources of nutrients and sediments.

Density Targets

For all habitat areas delineated within the tiered SAV distribution restoration targets, the Chesapeake Bay SAV density restoration target is to maximize the amount of SAV present with coverage within the 70-100% density category of the crown density scale used in the Chesapeake Bay SAV Aerial Survey Program (Orth *et al.* 1991).

The 1990 SAV distributional survey delineated 11,243 hectares of bottom that were classified as dense (70-100% coverage based on Orth *et al.* 1991), or 46% of the total SAV mapped for the Bay and tributaries in 1990. This represents 24% of the SAV Density Restoration Target for the SAV Tier I Distribution Restoration Target. Areas with significant coverage in this density class are CB5–24% (Lower Chesapeake Bay), CB6–39% (Western Lower Chesapeake Bay), WE4–45% (Mobjack Bay), EE3–48% (Tangier Sound), TF2–38% (Upper Potomac River), and RET2–45% (Middle Potomac River). These data for the density restoration targets contrast with the Tier I target percentages. This is because several of the segments, despite high percentages for Tier I, had very sparse coverage and thus much lower estimates for the density restoration target-notably the upper Chesapeake Bay area for the Susquehanna Flats and the Elk and Bohemia rivers. All segments with the highest percentages in the density restoration targets are in the lower Chesapeake Bay, along both the eastern and western shores, reflecting the better water quality in the mainstem of the Bay and in the Potomac River where *H. verticillata* and other native species have rapidly recolonized the shoals over the last seven years.

Species Distribution and Diversity Targets

Baywide and regional targets for Chesapeake Bay species distribution and diversity were developed based on both present and historical SAV distribution patterns (see Chapter VI for the species distribution restoration target maps). Species distribution information was synthesized from surveys of present SAV, pollen and seed records, and literature documenting historical distributions. Achievement of these species specific distribution and diversity restoration targets through repropagation to their distribution limits (salinity tolerances) are based on meeting the SAV habitat requirements on a baywide basis, the presence of sufficient propagules and other environmental factors limiting growth (e.g., temperature, sediment substrate and herbicides) remaining within the tolerance limits of the SAV species.

Development of the recent and potential distribution maps for each species revealed that even though many of the native species are still present in the Bay, all species, in particular the freshwater species, have significantly different baywide distribution patterns than what was observed historically. An exception is the recent arrival and spread of the non-native *H. verticillata* in the Potomac River. Some once very common SAV species (e.g., *Potamogeton perfoliatus* and *Elodea canadensis)* are now extremely scarce. The diversity of plants in different sections of the Bay is also very low. Many areas once dominated by four or more species now have only one. This low diversity is suggestive of a system in an earlier successional stage where species with both high growth and reproductive rates dominate. Disturbed systems, because of continual perturbations, are normally maintained in an early successional phase. Exotic species with very high growth and reproduction rates generally outcompete native species, principally by competitive exclusion, as in the case with the spread of *M. spicatum* in the upper Bay in the 1960s. (Bayley *et al.* 1978).

Chapter V

Regional SAV Study Area Findings

Four submerged aquatic vegetation (SAV) study areas were used to develop specific relationships between SAV survival and water quality (Figure V-1). These areas represent regions of intensive SAV studies over the past decade in which water quality data and SAV growth, distribution, density, and transplant data were available. Empirical relationships between water quality characteristics and SAV distributions provided the means of defining habitat requirements for SAV survival. It is the application of these SAV/water quality relationships from the case studies in different regions of Chesapeake Bay by different investigators over the span of several years that forms the basis of the SAV habitat requirements.

Locator Map of SAV Study Areas

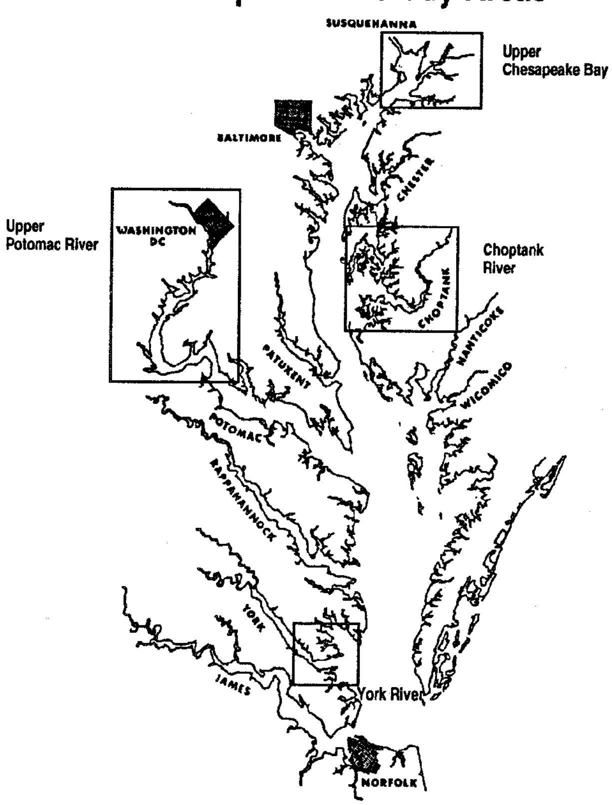


Figure V-1. Locations of the four regional SAV study areas–upper Chesapeake Bay, upper Potomac River, Choptank River, and York River.

Background

Upper Chesapeake Bay

The upper Chesapeake Bay, which includes the Susquehanna Flats and the Elk, Sassafras, Northeast, and Susquehanna rivers, is a region characteristic of tidal fresh and oligohaline areas. Like most other tidal fresh and oligohaline areas, populations of SAV are currently at very low levels (Orth *et al.* 1989) compared to previous periods (Bayley *et al.* 1978).

Historically, studies of SAV in this area focused on population level fluctuations in the distribution and density of both native and introduced species such as *M. spicatum* (Stotts 1970; Steenis 1970; Bayley *et al.* 1978). Prior to 1957, the Susquehanna Flats, a shallow area (<3 meters (m) in depth) located at the mouth of the Susquehanna River, was populated with a diverse community of approximately 13 SAV species that covered nearly 4,000 hectares (these figures do not include the beds previously located in the Elk, Sassafras, Northeast, or Susquehanna rivers). Between 1959 and 1961, however, *M. spicatum* reached nuisance levels—49% of the stations sampled by Bayley *et al.* (1978) were vegetated with that species. After competitive exclusion of the native species, *M. spicatum* subsequently declined for unknown reasons. Native vegetation returned but at lower densities and lesser abundances than before the invasion. Changes in the region triggered by Tropical Storm Agnes in 1972 resulted in a nearly complete loss of vegetation. Causes for the decline and lack of regrowth, while perhaps initiated by storm events, may have been largely due to increasing background levels of turbidity and nutrients from agriculture and urbanization of the surrounding watershed. Study results presented here focus on developing an understanding between these factors and SAV survival.

Presently, *M. spicatum* is the most widely distributed SAV species in the tidal fresh and oligohaline waters of the upper Chesapeake. It occurs at deeper depths (up to 2 m) than any other species except *Ceratophyllum demersum*, which is one of the most tolerant species of low light conditions

(Van *et al.* 1976). *Potamogeton crispus and M. spicatum* are able to inhabit slightly deeper waters because they initiate growth early in the season when waters are less turbid. By early summer, their leaves are at the water surface, absorbing unattenuated light.

Upper Potomac River

The tidal Potomac River and Estuary are regions where scientists have documented and examined dramatic changes in SAV distribution. Historically, the tidal Potomac River contained numerous SAV species (Haramis and Carter 1983; Carter *et al.* 1985a). A 1916 map of the upper tidal fresh zone of the river from Washington, D.C. to below Marshall Hall (at low tide) shows a narrow channel and wide, shallow, vegetated margins or flats containing beds of *P. crispus, C. demersum,* and *V. americana* (Cumming *et al.* 1916). Species identified in the freshwater tidal river before the disappearance of plants in the late 1930s include: *V. americana, C. demersum, Najas flexilis, Elodea canadensis, P. crispus,* and *Najas guadalupensis.* Populations of SAV in the tidal Potomac River declined or disappeared during the late 1930s (Martin and Uhler 1939; Elser 1969; Stevenson and Confer 1978; Bartsch 1954; Stewart 1962; Haramis and Carter 1983; Carter *et al.* 1985a; Rybicki *et al.* 1988; Orth *et al.* 1979). Losses were greatest in the tidal river and the mesohaline reach of the estuary. Bartsch (1954) and Stewart (1962) reported that the freshwater tidal reach of the Potomac River was devoid of SAV. Stewart found an abundance of plants in the central Potomac (between Maryland Point and the Route 301 bridge) but reported only narrow zones of SAV in the mesohaline reach of the estuary. In 1972, 1973, 1977, and 1978, the U.S. Fish and Wildlife Service found no SAV in the tidal river; only 4% of 150 sampling stations in the tidal river and estuary were vegetated (Haramis 1977; personal communication, G.M. Haramis, FWS 1978). No comprehensive survey of SAV in the tidal Potomac River, however, had been conducted prior to 1978.

A U.S. Geological Survey (USGS) /U.S. Fish and Wildlife Service survey in 1978–1981 found a few small isolated populations in tributary mouths and in the mainstem tidal river (Haramis and Carter 1983; Carter *et al.* 1985a). In 1983, however, following a period of improvements in wastewater treatment and during a year with unusual weather, there was a resurgence of SAV in the upper tidal river (Carter and Rybicki 1986). Carter and Rybicki (1986) found 13 species, including two previously unreported species–*H. verticillata* and *Heteranthera dubia*. Coverage of SAV has increased in the tidal river since 1983. SAV has persisted in the oligohaline to mesohaline transition zone of the Potomac Estuary from the 1930s to the present. To date, there has been no significant recovery of SAV in the mesohaline estuary.

The pattern of decline and sustained absence of SAV from the 1930s through 1981 can be linked to changing nutrient and sediment conditions in the tidal Potomac River. Investigators believe that these conditions combined with extensive storm damage in the late 1930s led to the demise of SAV (Carter *et al.* 1983; Rybicki and Carter 1986). The tidal Potomac River receives nearly all the municipal sewage discharged from advanced-waste sewage treatment plants that serve the population of three million in the Washington, D.C. metropolitan area (Callender *et al.* 1984). Nutrient loading to the Potomac River increased drastically from the early 1900s until 1974 when tertiary treatment to remove phosphorus was begun (Jaworski *et al.* 1971; Callender *et al.* 1984). This was followed by the introduction of nitrification in 1980, which removed additional phosphorus and converted ammonia to nitrate (Callender *et al.* 1984). Sedimentation has long been a problem in the Potomac as well (Feltz and Herb 1978; Callender *et al.* 1984). Subsequent transplant and water quality studies in the Potomac River and Estuary gave credence to the hypothesis that light penetration was the limiting factor in the establishment and survival of SAV.

Using *V. americana*, USGS scientists made a series of transplants in the tidal river from 1980–1983 and found that the plants survived in some sites with light attenuation ≤ 2.7 m^{-1} if protected from herbivore grazing during the first year after transplanting (Carter and Rybicki 1985). Investigators generally attributed the lack of SAV in the region to a combination of nutrient enrichment and high levels of total suspended solids which limited light needed for plant photosynthesis (Carter *et al.* 1985a; Carter and Rybicki 1986).

In 1983, SAV returned to the upper tidal Potomac River. Its distribution and density increased through 1988 (Carter and Rybicki 1986; Orth *et al.* 1987; Rybicki *et al.* 1988). After 1986, SAV spread into the lower tidal river, reestablishing in many areas. From 1985-1986, USGS scientists made a detailed study of the underwater light environment in the upper and lower tidal freshwater areas and the oligohaline transition zone during two growing seasons (Carter and Rybicki 1990). Results indicated that light attenuation in the unvegetated lower tidal river was greater than light attenuation in the upper tidal river where SAV was present.

Choptank River

The Choptank River, the largest tributary on the eastern shore of Chesapeake Bay, has served as the site of several studies on SAV mid-Bay mesohaline communities. In the early 1970s, the lower Choptank shallows were dominated by a variety of SAV species including *Ruppia maritima, Potamogeton perfoliatus, Potamogeton pectinatus, M. spicatum,* and *Zannichelia palustris* (Stevenson and Confer 1978). During the 1970s, Stevenson and Confer (1978) estimated that 41%, or approximately 15,000 hectares, of the Choptank River littoral zone was vegetated with SAV. By 1987, Orth *et al.* (1989) reported that only 350 hectares were vegetated.

Heinle *et al.* (1980) categorized water quality at the mouth of the Choptank River and the adjacent Bay as moderately enriched with nutrients and occasionally high chlorophyll *a* levels. Upriver areas of the Choptank River and Tuckahoe Creek have been increasingly affected by point and non-point source runoff (Ward and Twilley 1986). In this region, the tidal river is considered eutrophic and is characterized by high levels of turbidity and chlorophyll *a* (Lomax and Stevenson 1982).

Using principally *P. perfoliatus* and *R. maritima*, Twilley *et al.* (1985) grew SAV in experimental ponds which were filled with water pumped directly from the Choptank River. These ponds were dosed with dissolved nutrients (nitrogen and phosphorus) at three concentrations in addition to an untreated control pond. Seston (particulate suspended matter) and phytoplankton chlorophyll *a* levels increased with fertilization – pronounced algal blooms occurred with higher dosages of fertilization. Of the total seston, phytoplankton had the greatest influence on light attenuation with light levels at the sediment surface were reduced below the compensation point for SAV. An extensive epiphytic community developed on plants in all nutrient-treated ponds. The epiphytes in the highest dosage treatments attenuated >80% of the incident light at the leaf surface. Compared to control and low treatments, biomass of the SAV decreased significantly under high and medium nutrient treatments within 60 days of initial fertilization. Most of the decrease in SAV photosynthesis could be explained by attenuation of light associated with epiphytic loadings. Without light attenuation in the overlying water column, however, epiphytic growth appeared insufficient to reduce light below compensation levels. This experiment, along with other studies where nutrients and light were manipulated under controlled conditions (Staver 1985; Goldsborough and Kemp 1988), helped isolate the mechanisms behind the SAV decline.

During 1987 and 1988, scientists at the University of Maryland Horn Point Environmental Laboratory (HPEL) conducted three experiments investigating the relative responses of SAV and epiphyte growth to additions of nitrogen versus phosphorus in brackish and more saline regions of the Chesapeake Bay. In two of these studies, they added nitrogen and phosphorus at various rates and ratios to water columns of replicate mesocosms containing in one case the brackish water plant, *P. perfoliatus,* and in the other case the marine SAV species *Zostera marina*. In these experiments, which simulated the eutrophication of the Bay's shallow mesohaline and polyhaline waters, they monitored epiphytic algae and phytoplankton, nutrient concentrations, and SAV growth and abundance. In the other set of studies, nitrogen and phosphorus were added to sediment pore waters in field sites containing *Z. marina* to test the potential stimulation of SAV growth (i.e., "nutrient limitation") by nitrogen and/or phosphorus. In addition, rates of nitrogen and phosphorus recycling and microbial transformation processes were measured in sediments at these field sites. These studies have provided important information of the direct and indirect responses of SAV ecosystems in shallow waters around the Bay to nitrogen and phosphorus enrichment.

Both nitrogen and phosphorus additions (equivalent to a 100-fold increase) to the water columns of experimental mesocosms containing *P. perfoliatus* resulted in significant increases (275–350%) in the biomass of epiphytic algae on the plant leaves. Phytoplankton biomass also increased by a factor of about 10–15 times from low to high nitrogen and phosphorus additions. Growth of *P. perfoliatus* decreased by about 60% in response to additions of both nutrients. Light attenuation by epiphytic algae was sufficiently great at high nutrient treatments to explain most of the decrease in plant growth, suggesting that both nitrogen and phosphorus can be important in limiting SAV growth in the upper regions of the Bay.

York River

Zostera marina is the dominant SAV species in the mesohaline and polyhaline regions of the lower Chesapeake Bay. Historically, extensive SAV beds covered the shoal areas of the mainstem of the Bay and the eastern and western shore tributaries where salinities averaged greater than 10 parts per thousand. Beginning in the late 1960s, however, a dieback was observed in these polyhaline SAV beds, coinciding with a general dieback in SAV throughout the Bay system. Losses were greatest in western, upriver areas and the deeper channelward limits of the SAV beds. This pattern of dieback suggested that the losses might be associated with increasing river discharge and that the factors limiting SAV survival were less important with increased mixing of oceanic water (Orth and Moore 1983).

Although *Z. marina* was the dominant species in these polyhaline SAV beds, *R. maritima* co-occurred in many areas and was the dominant species in the shallowest zones (Marsh 1970; Orth and Moore 1988). This pattern suggests that either the same limiting factors were involved or that loss of *Z. marina* from the deeper, channelward zones had a deleterious effect on the survival of *R. maritima* grass bordering the shoreline. Therefore *Z. marina* was chosen as the species used to develop relationships between habitat quality and SAV survival in this region.

The lower York River was chosen as a study area since it was characteristic of SAV decline in the polyhaline region of the Bay, and a number of ongoing projects were being conducted there. Within a relatively small area, the lower York River had sites that experienced complete dieback, partial dieback, or only a minimal SAV loss. This estuary is characterized by broad, shallow flats extending landward from a relatively deep, narrow channel.

Historical photography revealed that SAV beds, prior to 1971, were located along both shorelines of the river at depths of approximately 2 m or less. They extended from the mouth of the estuary upriver 25 km to the average 10 parts per thousand isohaline at Claybank. Studies from the region (Marsh 1970; 1973; Orth 1973) and empirical observations indicate that the SAV beds which declined were dominated by *Z. marina* with some *R. maritima* occurring at the shallowest inshore sections of the beds. Between 1971 and 1974, SAV disappeared from all locations upriver of Gloucester Point and from the deeper, channelward sections of the beds at or downriver of this area (Orth *et al.* 1979). Since that time, there has been some recovery of beds downriver of Gloucester Point, as seedlings of *Z. marina* spread into areas immediately adjacent to existing beds; however, there has been no substantial regrowth into areas upriver of this point.

There have been some studies relating SAV growth in the polyhaline, lower Bay with water quality. Results from a lower Bay experiment with *Z. marina* by HPEL scientists were considerably different than those for upper Bay species (Nuendorfer 1990). In the lower Bay, phosphorus additions caused little growth increases of epiphytes or phytoplankton and had no effect on plant growth. Nitrogen additions, however, resulted in dramatic increases in epiphyte biomass and small decreases in plant growth. The relatively small reduction in *Z. marina* growth may have been a consequence of the fact that light availability under experimental conditions was greater than in the field, so that attenuation due to algal growth was insufficient to bring light below growth-saturated levels. Changes in nutrient treatment rates and nitrogen:phosphorus ratios caused significant alterations in the taxonomic composition of the epiphytic community. The alterations resulted in significant changes in the rate of experimental grazing by two different species of invertebrates (a gastropod and an isopod). The results indicate that nitrogen is more important than phosphorus in stimulating the growth of epiphytes and, therefore, inhibits SAV growth in the lower Bay communities. Changes in the nitrogen: phosphorus ratio, however, can affect the epiphyte composition and susceptibility to grazing.

Additions of both nitrogen and phosphorus to sediment pore waters of *Z. marina* communities resulted in marked increases in both biomass and plant growth of experimental plants. The greatest growth responses occurred with additions of both nitrogen and phosphorus. Even though light levels at the sediment fertilization field sites were generally below conditions needed to saturate *Z. marina* growth, these results indicate that the SAV were limited by insufficient sediment nutrients.

Studies in Virginia, in which nitrogen and phosphorus were added to the sediments of transplanted *Z. marina*, demonstrated that plant growth may be nutrient limited (Orth and Moore 1982). While increased sediment nutrient availability may initially promote growth, it does not create conditions for long-term survival (Orth *et al.* 1982). This finding suggests that while sediment condition, including the availability of nutrients, may contribute to SAV loss, differences in water column factors between sites are likely the primary mechanism responsible for differences in SAV survival.

The patterns of SAV decline observed between 1965 and 1980 (Orth and Moore 1984) support this hypothesis. SAV beds declined from areas with a wide variety of sediment types, including both exposed, sandy areas with low interstitial nutrients and high redox potentials, and sheltered, organic-rich areas with higher nutrient levels and lower redox. The declines were greatest in upbay and upriver areas of the western tributaries, closely paralleling the pattern of nutrient enrichment. In areas where the vegetation did not completely disappear, it was generally the deeper, channelward regions which died back. These observations suggest that water quality factors which become more pronounced with increasing depth may be responsible for the SAV declines.

The following four regional study areas span the range of salinities, from tidal freshwater in the Susquehanna Flats and Potomac River to the highest salinity areas near the Bay's mouth. They are presented in order of increasing salinity from the upper Chesapeake Bay and upper Potomac River to the Choptank River and finally the York River.

Upper Chesapeake Bay

SAV habitat requirements for tidal fresh and oligohaline regions of the upper Chesapeake Bay were developed by relating water quality parameters with the presence or absence of healthy SAV populations and by determining whether or not SAV transplants were successful under particular water quality regimes. While correspondences between SAV survival and growth with factors such as light attenuation (measured as light attenuation coefficient and Secchi depth), chlorophyll *a*, and total suspended solids were clear, determining nutrient levels at which SAV grow and survive proved more difficult.

The sites that were selected for nutrient sampling and analyses were changed during each of the first three of five years to obtain a broader picture of upper Bay water quality. Thus, there was no yearly progression of data to evaluate from all sites until years four and five. Second, because epiphytic growth was not evaluated or characterized, the degree to which their population growth and densities were influenced by nutrient levels was not determined. In some instances photosynthetically active radiation reaching leaf surfaces may have been significantly altered by epiphytic growth. Third, monthly measurements of water quality do not adequately characterize the dynamic nature of nutrient concentrations in the upper Bay. Important pulses or events may have been missed due to sampling dates spaced too far apart. Despite these inconsistencies, correspondences were developed between the parameters studied and the presence or absence of SAV.

Study Area

The upper Chesapeake Bay region is defined here as the area ranging from the mouth of the Susquehanna River south to the Bush River on the western shore and to Still Pond Creek on the eastern shore. The study area also includes the Elk River to the C&D Canal and the Sassafras River along its entire length. The most abundant SAV populations with the greatest cover in the upper Bay are currently located at the mouths of the Susquehanna and Sassafras rivers and intermittently along the north shore of the lower Elk River. These areas, especially the river mouths, regularly have the greatest light penetration compared to other locations around the upper Bay.

From August-October of 1987, June-October of 1988, and April-October of 1989, 24 water quality stations (Table V-1 and Figure V-2) were monitored monthly for temperature, pH, Secchi depth, dissolved oxygen, salinity, nitrate, ammonia, dissolved inorganic phosphorus, total phosphorus, and chlorophyll *a*. All sites were selected to provide a spectrum of upper Bay water quality information in regions where transplants were being performed and for the purpose of comparing water quality conditions along transects. Since the 1987 data reflect only the latter portion of the growing season, their analysis has not been included here.

In 1989, direct measurement of the light attenuation coefficient was added to the list of parameters, and the monitoring was expanded to include eight additional stations (Table V-1 and Figure V-2) to better characterize upper Chesapeake Bay and Sassafras River water quality conditions. In 1989, samples from all Sassafras River stations (Howell Point, Betterton, Lloyd's Creek, Marsh Neck [in], Marsh Neck [out], Ordinary Point, Confluence, Daffodil Island, Georgetown, Jacob's Creek, Duffy Creek, and Grove Neck [in]) were split with HPEL and analyzed for nitrate and nitrite, ammonia, dissolved inorganic phosphorus, total phosphorus, and total suspended solids.

Methods

<u>Transplant Experiments</u>

Since 1984, various techniques for transplanting *V. americana* have been tested (Kollar 1985, 1986, 1987, 1988). In general, transplants utilizing Wisconsin grown stock or locally grown turions planted in the spring or fall were not successful. Transplanting mature stock using posthole diggers was laborious, time consuming, and ineffective. The most successful method involved harvesting mature plants by plunging both hands deep into the sediments and shaking them rapidly while lifting as much root, stolon and plant material as possible. When replanted, unbroken stolons were gently wrapped around one another in a loose circle in groups of approximately 150 plants per square meter. Every other square meter was skipped, creating a checkerboard pattern of high density plots which would eventually grow together if the transplants were successful.

Transplant success was monitored weekly to biweekly after placement and several times a year after the first successful growing season. The definition for transplant

Table V-1. Upper Chesapeake Bay SAV habitat monitoring stations.

Station Number	Station Name	Years Sampled	SAV Status [1]	Latitude	Longitude	Transplant Status [3]
1	Log Pond	1987-1989	P(2)	39°32'39"	76°05'00"	-
2	Outfall/Havre de Grace	1987-1989	F	39°31'53"	76°05'15"	-
3	Fishing Battery (in)	1987-1989	P(2)	39°29'40"	76°05'07"	S(2)
4	Fishing Battery (out)	1987-1989	P(2)	39°29'37"	76°05'12"	-
5	Central Bay	1987-1989	-	39°27'47"	76°02'57"	-
6	Howell Point	1989	-	39°22'34"	76°06'40"	-
7	Betterton	1989	F	39°22'26"	76°03'45"	M(1)
8	Lloyd's Creek	1987-1989	-	39°21'43"	76°01'32"	F(2)
9	Marsh (in)	1987-1989	F	39°22'04"	75°59'26"	S(1)
10	Marsh (out)	1987-1989	-	39°22'04"	75°59'16"	-
11	Ordinary Point	1987-1989	P(2)	39°22'21"	75°58'49"	S(1)
12	Confluence	1987-1989	-	39°22'26"	75°56'54'	F(1)
13	Daffodil Island	1987-1989	-	39°21'57"	75°55'09"	F(2)
14	Georgetown	1987-1989	-	39°21'49"	75°52'59"	F(1)
15	Jacob's Creek	1987-1989	-	39°22'16"	75°50'26"	-
16	Duffy Creek	1989	-	39°22'37"	75°49'46"	-
17	Grove Point Marsh (in)	1987-1989	P	39°23'05"	76°01'07"	M(4)
18	Sassafras Mouth	1987-1989	F	39°23'08"	76°02'44"	M(1)
19	Elk River Mouth	1987-1989	-	39°26'29"	75°59'43"	-
20	Cabin John Creek (in)	1987-1989	-	39°27'20"	75°56'40"	F(2)
21	Cabin John Creek (out)	1987-1989	-	39°27'42"	75°57'37"	F(2)
22	Bohemia River	1887-1989	-	39°28'32"	75°54'39"	-
23	Piney Creek (in)	1987-1989	F	39°30'45"	75°55'42"	F(2)
24	Piney Creek (out)	1987-1989	-	39°30'29"	75°55'13"	-
25	Elk Neck (in)	1987-1989	P	39°28'50"	75°58'02"	S(3)
26	Elk Neck (out)	1987-1989	F	39°28'50"	75°57'49"	-
27	Rocky Point	1989	-	39°28'43"	76°00'23"	-
28	Northeast River	1989	-	39°32'05"	75°59'33"	-
29	Furnace Bay	1989	-	39°33'01"	76°02'47"	-
30	Grass Flats	1989	F	39°32'16"	76°01'33"	F(6)
31	Perry Point	1989	P(2)	39°33'06"	76°04'38"	S(2)
32	Grove Neck Marsh (out)	1987-1989	F	39°22'54"	76°01'13"	-

(1) Relative SAV abundance in the vicinity of the monitoring station from 1987-1989: P = persistent SAV; F = fluctuating SAV; - = SAV absent.
(2) SAV persistent in the vicinity of the monitoring station in 1988, but SAV was fluctuating or absent in 1989.
(3) Status of SAV transplants in the vicinity of the monitoring station 1984-1988: S = successful transplant; F = failed transplant; M = marginal transplant; - no transplants attempted; numbers in parentheses indicates the number of areas transplanted.

success changed during the first two years of the project. During the first year, any plot in which at least 50% of the plants survived was considered successful; in the second year at least 50% of the plants had to produce at least one new plantlet and survive for two successive growing seasons. This definition has remained with the stipulation that a healthy, successful transplant plot fill in and expand its range. Healthy *V. americana* plants have been observed to produce as many as 17 new plantlets in a growing season under optimum conditions.

Water Quality Monitoring

Dissolved oxygen and temperature readings were made *in situ* using a YSI model 51B D.O. meter while pH was determined using a Corning model 105 pH meter. Light attenuation coefficient measurements were made just below the surface, at the 0.5 m and 1 m depths using a LICOR LI 1000 Datalogger with LI 1925A underwater quantum sensor. Water column samples were collected at the 0.33 m depth, filtered through a 0.45 micron GFC glass filter (1989 only), and analyzed immediately upon return to the lab. Nitrate and ammonia levels were determined using an Orion 407B Ionalyzer with respective electrodes. Dissolved inorganic phosphorus was read via direct colorimetry. Absorption was determined using a Bausch and Lomb

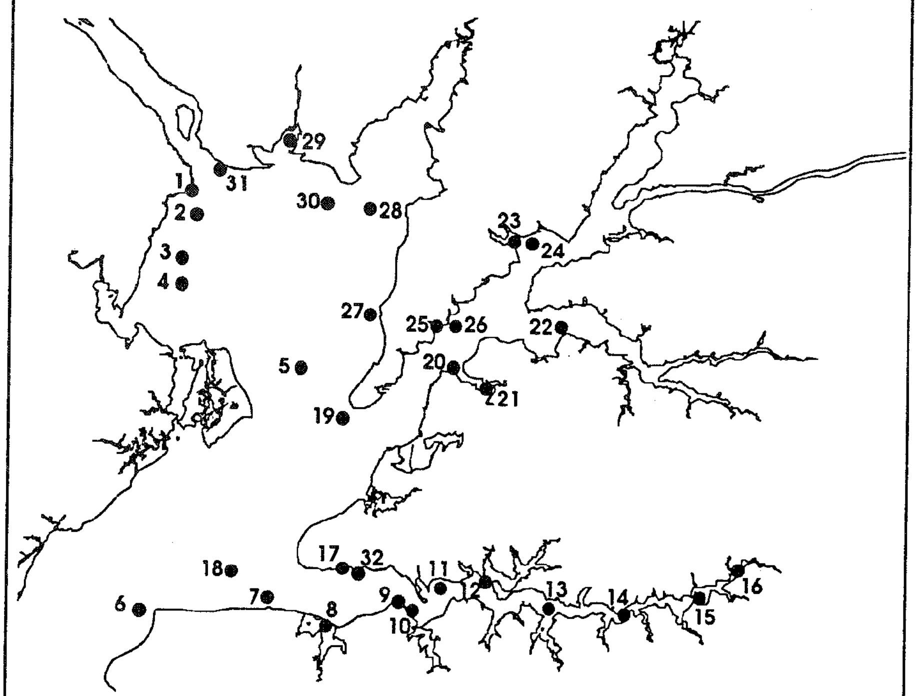


Figure V-2. Location of the upper Chesapeake Bay SAV habitat monitoring stations.

Spectronic 20 spectrophotometer with a light path of 2.5 cm. Total phosphorus was determined using acid hydrolysis and persulfate digestion with ascorbic acid as a colorimetric indicator.

Accuracy problems arose with the use of the ion specific nitrate electrode. Despite checking every fifth sample against a known standard and beginning each sample run against an EPA nutrient performance audit sample, the readings appear to be high by approximately 0.5 - 1.5 mg/l. Checks against split samples with the HPEL in 1989 revealed that the electrodes were apparently encountering a matrix interference with upper Bay samples. Therefore, only the nitrate and total nitrogen results from samples analyzed by HPEL in 1989 have been used to develop the SAV habitat requirements described here. Earlier nitrate data have not been utilized except to describe overall patterns from 1987–1989. Nutrient samples were checked frequently against known standards and the analytical systems were checked before and after each run against EPA reference standard samples. Methods used at HPEL in the analysis of the split samples from the Sassafras stations (1989 only) are described in the Choptank River section of this chapter. Chlorophyll *a* samples were analyzed fluorometrically by the University of Maryland Wye Laboratory (August 1987–June 1989) and HPEL (July 1989–October 1989). All soil particle-size analyses were determined using Bouyoucos standard hydrometers. Organic matter was ascertained using high temperature oxidation.

Results

Season Determination

V. americana begins to emerge from the sediments when water temperatures reach 15 °C. Plant growth does not accelerate until temperatures reach 20 °C or above. The ideal transplant window is approximately May 15 through August 1 with some success up until September 1. The more time the plants have to establish themselves, the more carbon can be allocated for turion formation which occurs from around August 15 through October 1. Critical periods in the life cycle of *V. americana* are April through early June (when emerging plantlets are growing towards the light) and late August through September (when turions are forming).

Transplant Experiments

Of 65 total transplant sites, 16 were considered marginal to successful with 9 sites defined as successful and healthy depending upon the year. Table V-1 lists water quality monitoring stations in the upper Chesapeake Bay where transplants survived. All of these successful and healthy sites–Perry Point I and II, and Elk Neck I, II, and III – were at river mouths, except Fishing Battery which is protected by a submerged breakwater. These areas were characterized by lower turbidity, chlorophyll *a*, phosphorus, and total suspended solid concentrations than the unsuccessful transplant sites. Sites at the mouth of the Sassafras River had pre-existing *M. spicatum* and *P. crispus* populations. Transplants there met with good to marginal success until 1989. Transplants in the upper Chesapeake Bay never survived where no other previously established SAV was in reasonable proximity.

Figure V-3 indicates transplant performance along an early (1985) transect in the Susquehanna Flats. At least three variables are involved here (depth, sediment, and wave energy). The plants grew optimally in the siltier sediments at depths (0.75–1.0 m) with adequate light penetration. Greater depths had lower light penetration. Shallower areas without SAV had substrates that were too sandy or sterile for growth. Wave energy or current velocity may also have been a factor, although *V. americana* has been shown to tolerate high energy environments very effectively (Titus and Adams 1979).

From early experiments, three criteria for transplant success were derived (Figure V-3):

1) a depth regime of 0.3 to 0.5 m Mean Low Water (MLW);
2) sediments that consisted of sandy silts or sandy loam with between 1% and 5% organic matter; and,
3) sites that afforded some degree of protection from high waves or currents.

In later experiments, transplants in the Sassafras River performed well only below Ordinary Point, specifically along the north shore with the exception of two small sites adjacent to Betterton. Repeated transplant attempts upstream from Ordinary Point failed even when plots were protected with snow fencing.

What all of the successful sites in the Sassafras River had in common was good water clarity. Secchi depth medians were always above 1 m with light attenuation < 2m^{-1}.

Total suspended solids medians were below 10 mg/l and chlorophyll *a* medians were generally below 10 µg/l except at stations 9 and 17. Ordinary Point (station 11) and Sassafras Marsh-In (station 9) were anomalous in that transplants could only be made in very shallow water (<0.6 m) which was often only 15 cm deep at low tide. Both sites were completely (Sassafras Marsh-In) or partially (Ordinary Point) surrounded by land. The calm, shallow water apparently allowed for better growth and establishment than would otherwise be achievable. At Grove Neck (station 17), existing M. *spicatum* and *P. crispus* populations continued to prosper when the chlorophyll *a* median rose above 15 µg/l in 1989, but the transplanted *V. americana* populations succumbed in 1989 after two years of success. One factor that the Sassafras sites lacked was an ideal substrate; they tended to be very high in sand with little or no silt.

At Elk Neck, three transplant plots were attempted and all achieved success. These plots were planted along the

Optimal Transplant Conditions on the Susquehanna Flats

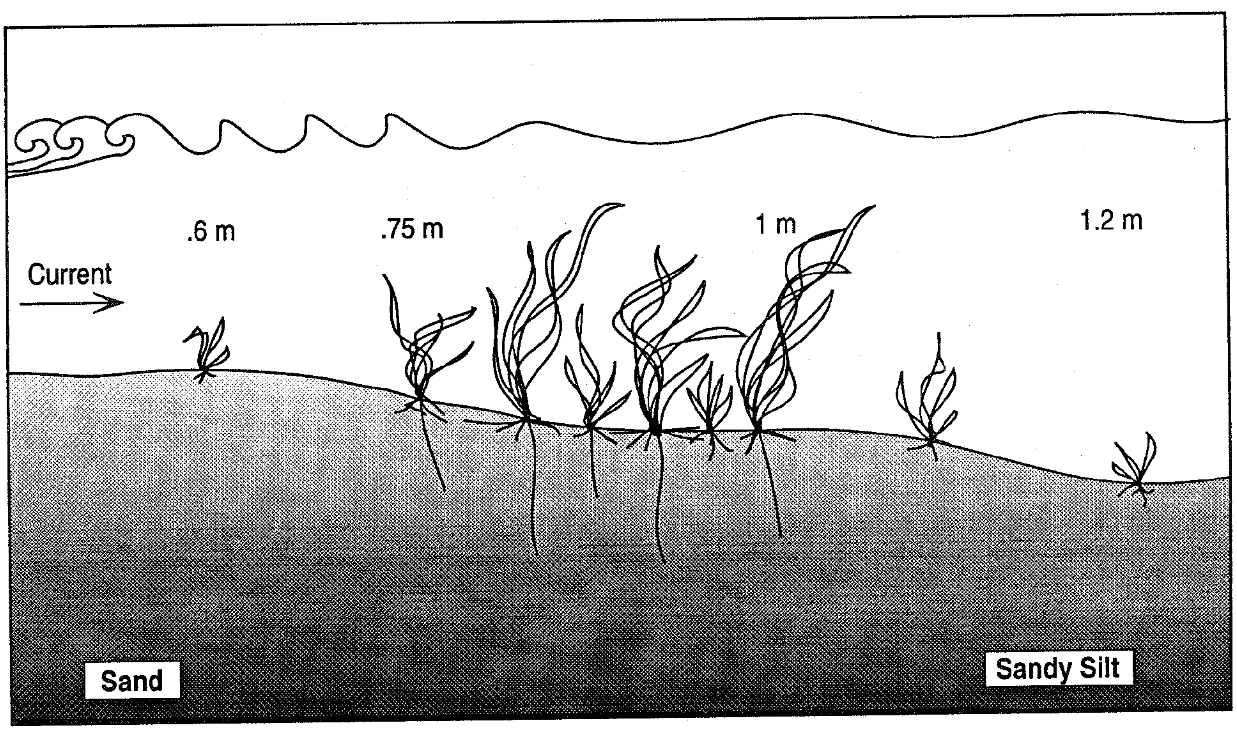


Figure V-3. The depth of the water column, sediment, and wave energy all influence transplant success and, ultimately, SAV survival and propagation. Optimal conditions displayed in this figure are a water column depth of 0.75–1.0m (0.3–0.5m MLW), sandy silt sediment, and low wave energy.

shoreline within a shallow embayment and were surrounded by an extensive bed of *M. spicatum*, which provided a good buffer against wave action. Total suspended solids medians were low (<8 mg/l) as were chlorophyll *a* medians (<8 µg/l), and the light attenuation coefficient was <2 m^{-1} in 1989. Secchi depth often could not be measured due to the shallow water. The protected shallow habitat provided ideal conditions for the growth of *V. americana*. Within two years, plots that were 1 m^2 had expanded to approximately 3 m^2, forming very dense beds. Other more exposed sites along the Elk shoreline did not demonstrate the same potential for SAV reestablishment. Light attenuation coefficients at all of the other sites monitored in the Elk River had growing season medians above 2 m^{-1} with the exception of Elk Mouth (station 19, see Figure V-8) which contained a marginal transplant plot.

At Perry Point (station 31), along the north shore of the Susquehanna River mouth, native SAV populations declined during 1989, except for *V. americana* transplants which did very well despite a growing season median light attenuation coefficient of 2.25 m^{-1} (see Figure V-8). Total suspended solids and chlorophyll *a* seasonal medians were low–7.3 mg/l and 6.6 µg/l, respectively. It should be noted that the light attenuation coefficient and Secchi depth readings may not be directly applicable here since monitoring was applied just outside the shoal area where planting occurred. The calmer waters over the shoal were probably slightly clearer. Also, a snow fence was used around these plants to exclude carp, which can have a devastating effect on new transplants. The fencing, though loosely constructed, could have had an ameliorating effect on wave action and turbidity.

At all the successful transplant sites, growing season median water quality conditions varied slightly but usually included: Secchi depth >1 m, light attenuation coefficient <2 m^{-1}, total suspended solids <15 mg/l, chlorophyll *a* <15 µg/l, and dissolved inorganic phosphorus <0.02 mg/l. While these were not the only factors required for transplant success at all sites, when growing season medians exceeded these levels, the transplants performed poorly or failed.

Water Quality Parameters

Temperature

While species such as *M. spicatum* and *P. crispus* begin growing when light is sufficient and water temperatures are above 5 °C, *V. americana* growth does not begin until ambient temperatures are between 15 °C to 20 °C, with rapid growth not beginning until temperatures reach 25 °C (optimum temperatures are between 30 °C to 35 °C). Thus, in late April or early May when water temperatures are between 15 °C and 20 °C., *M. spicatum* and *P. crispus* are usually breaking the water surface when *V. americana* is just beginning to grow

Temperatures in upper Chesapeake Bay waters peak between late July and late August depending upon cloud cover, light, and air temperature. The drought years of 1987 and 1988 brought warmer temperatures to upper Bay waters from June through August, compared to 1986 and the cloudy, rainy year of 1989. While June temperatures normally average between 23.5 °C and 27.5 °C, 1989 weather conditions caused average temperatures of only 21 °C which, along with high turbidity, seriously compromised the ability of *V. americana* populations to flourish.

Normal growing season temperature averages for the upper Chesapeake Bay are as follows for surface water: April–15 °C, May-20 °C, June-25 °C, July-27 °C, August-26 °C, September-18 °C, and October-13 °C. Thus, it can be seen that *V. americana* normally achieves most active growth during the months of June, July, and August with turion formation occurring in August and September.

Temperature profiles are of course dependent upon water depth, currents, surrounding terrain, and other factors. It is possible one of the reasons that transplants of *V. americana* performed reasonably well at Ordinary Point and Sassafras Marsh was that the calm, shallow waters held higher temperatures longer than normal thus compensating for high chlorophyll *a* and total suspended solid concentrations during the main growing season.

Salinity

Within the Susquehanna Flats, salinity levels were nearly always 0–1 parts per thousand (ppt). In the Elk and Sassafras rivers, salinity levels of 1–2 ppt were most common, dropping to 0 ppt above Ordinary Point in the Sassafras River.

Light Attenuation

In 1987 and 1988, water transparency was measured at upper Chesapeake Bay stations using a Secchi disk. During the 1989 monitoring year, direct measurements of light attenuation coefficients were included as well. For most sites, a growing season median Secchi depth of greater than 1.0 m was associated with the presence of persistent SAV (Figures V-4 through V-8).

At a few very sheltered sites such as Ordinary Point (station 11 on Figures V-4 and V-5) and Elk Neck (station 25 on Figure V-6) lower light attenuation coefficient values were noted. The presence of SAV at these sites is explained by the reduced stress encountered by the

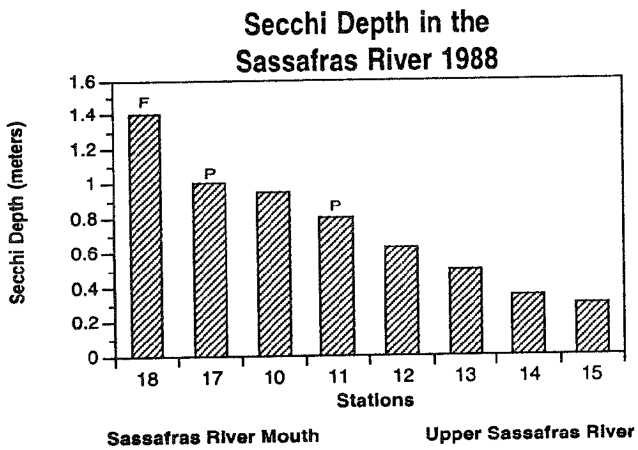


Figure V-4. Growing season 1988 median Secchi depths from the mouth of the Sassafras River upstream. P=Persistent SAV; F=Fluctuating SAV; remaining sites were unvegetated.

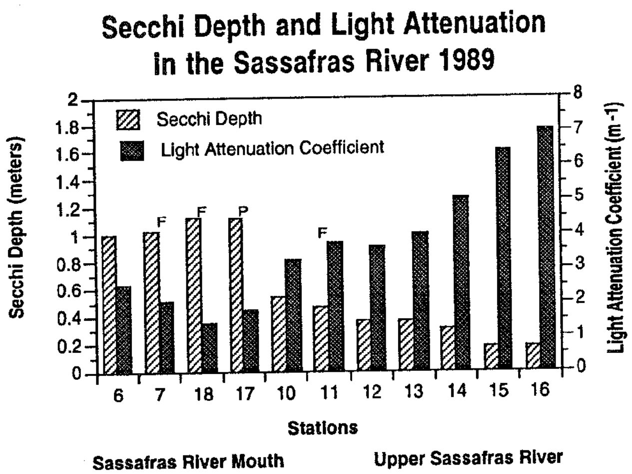


Figure V-5. June–October 1989 median Secchi depth and light attenuation coefficient measurements from the Sassafras River mouth upstream. P=Persistent SAV; F=Fluctuating SAV; remaining sites were unvegetated.

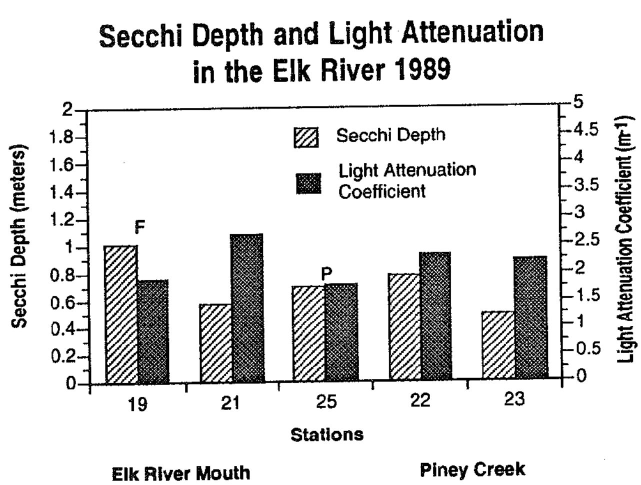


Figure V-6. June–October 1989 median Secchi depth and light attenuation coefficient measurements in the Elk River. P=Persistent SAV; F=Fluctuating SAV; remaining sites were unvegetated.

plants as a result of a sheltering spit at Ordinary Point and extensive *M. spicatum* populations at Elk Neck. Both factors induce calmer waters than would otherwise be found. The SAV are also growing in very shallow water (<0.6 m), which allows them to absorb more light than they would normally encounter under high turbidity conditions.

At Elk Neck, turbidity levels are dependent upon resuspension due to wave action. Most of the readings at Elk Neck (station 25) were obtained at low tide, when turbidity and wave action were greatest; therefore, the growing season median Secchi depth value of 0.70 m may not reflect a real average that the plants would experience throughout the day. The data show, however, that protected sites may sustain persistent SAV populations when Secchi depths drop as low as 0.7 m.

From the Sassafras River across the Susquehanna Flats to the Susquehanna River, Secchi depths averaged less in 1989 than in 1988 ($p<.05$), and SAV populations lost considerable biomass when compared to 1988. Spatial relationships also reversed themselves. While in 1988 Secchi depths were found to increase towards the Susquehanna River mouth (Figure V-7), in 1989 they became shallower (Figure V-8). Persistent SAV populations in either case were noted only when Secchi depths were greater than 1.0 m.

Along this transect, total suspended solids correlated with the Secchi depth in 1989 ($p<.05$), while chlorophyll *a* values did not. This infers that total suspended solids are more important than chlorophyll *a* in reducing light penetration at the Susquehanna River mouth area.

For reestablishment of SAV, the data from 1988 are revealing (Figure V-7). During 1987 and 1988, both considered drought years, V. *americana* seedlings were noted at stations 1 and 2, and transplants did well at station 18. At all of these stations, Secchi depths were >1.2 m. It should also be noted that from 1983 to 1990, V. americana only reproduced naturally via seeds in 1987 and 1988. Therefore, growing season median Secchi depths of at least 1.2 m are required for the expansion of *V. americana* populations in the upper Bay.

When light attenuation coefficient was directly measured during 1989, no persistent SAV populations were noted when growing season median light attenuation coefficient values were >2 m^{-1}. Many declining or fluctuating populations were noted at values between 1.85 m^{-1} and 3.8 m^{-1}. This was documented in both the Sassafras (Figure V-5) and Elk (Figure V-6) rivers. Despite the shallow depths which

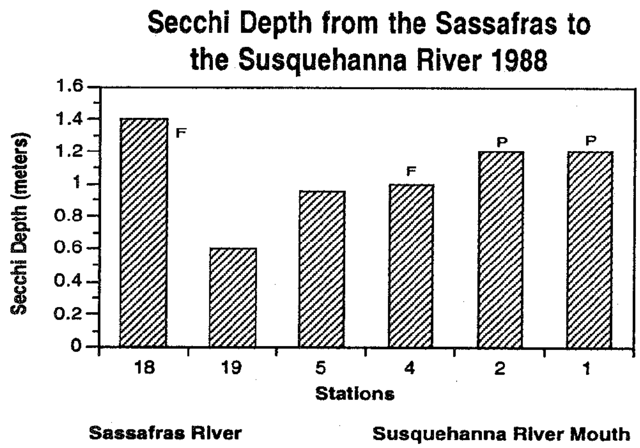


Figure V-7. Median 1988 growing season Secchi depth measurements along a transect of stations from the mouth of the Sassafras River through the Susquehanna Flats to the mouth of the Susquehanna River. P=Persistent SAV; F=Fluctuating SAV; remaining sites were unvegetated.

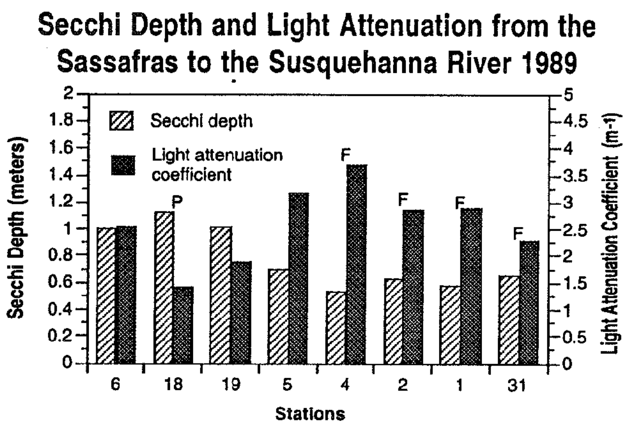


Figure V-8. June–October 1989 median Secchi depth and light attenuation coefficient measurements along a transect of stations from the mouth of the Sassafras River through the Susquehanna Flats to the mouth of the Susquehanna River. P=Persistent SAV; F=Fluctuating SAV; remaining sites were unvegetated.

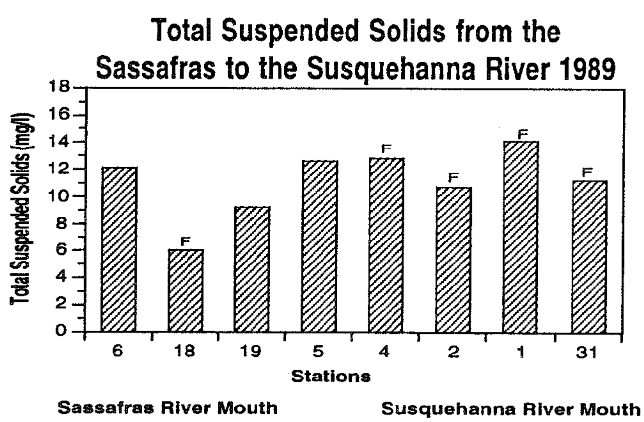


Figure V-9. May–October 1989 median total suspended solids concentrations along a transect of stations from the mouth of the Sassafras River through the Susquehanna Flats to the mouth of the Susquehanna River. P=Persistent SAV; F=Fluctuating SAV; remaining sites were unvegetated.

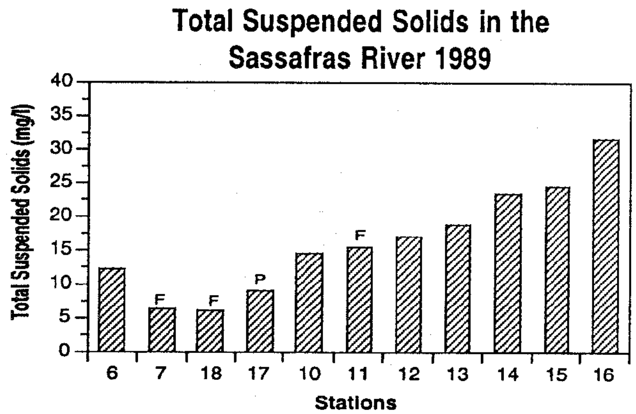


Figure V-10. May–October 1989 median total suspended solids concentrations from the Sassafras River mouth upriver. P=Persistent SAV; F=Fluctuating SAV; remaining sites were unvegetated.

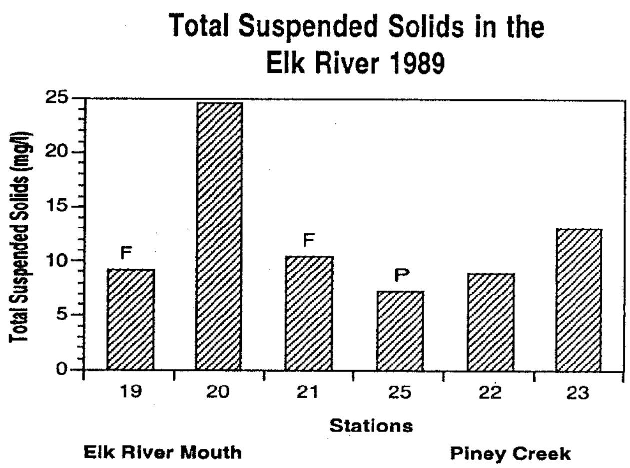


Figure V-11. May–October 1989 median total suspended solids concentrations in the Elk River. P=Persistent SAV; F=Fluctuating SAV; remaining sites were unvegetated.

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occur at station 11 (Ordinary Point), reduced light penetration caused a considerable SAV decline during 1989.

Along the Sassafras River to Susquehanna mouth transect (Figure V-8) in 1989, fluctuating SAV populations were found when growing season median light attenuation coefficient values were >2 m^{-1}. These sites (characterized by stations 1, 2, 4, and 31) previously had the most productive and persistent SAV beds in the upper Chesapeake Bay region but, in 1989, were in a state of severe decline when compared to 1988.

In Figure V-12, the presence of SAV is plotted against total suspended solids, chlorophyll *a,* and light attenuation coefficient. On these plots, no persistent SAV occured where growing season median light attenuation levels were >2 m^{-1}, where total suspended solid values were >15 mg/l, or where chlorophyll *a* exceeded 15 µg/l. Ordinary Point and Sassafras Marsh, the two sites with fluctuating SAV where water quality conditions slightly exceeded growing season medians, are the only prominent outliers in Figure V-12. At both of these sites on the Sassafras River, plants have been protected in shallow waters and receive virtually no wave action. The other marginal sites (Figure V-12), with light attenuation coefficient values >2 m^{-1}, are those at the mouth of the Susquehanna River which lost significant biomass when compared to 1988. Based upon these findings, a light attenuation coefficient level of 2 m^{-1} can be defended as an absolute maximum level at which SAV will grow and reproduce in tidal fresh and oligohaline waters of Chesapeake Bay.

While a Secchi depth to light attenuation coefficient conversion factor of 1.45 has been adopted, the applicability of this value at all times seems questionable in the waters of the upper Chesapeake. Suspended solids, humic acids, chlorophyll *a*, and other coloring agents have all been demonstrated to alter water transparency and light penetration. Although averages may yield a conversion factor of 1.45, specific situations may vary. In the Sassafras River, for example, the most transparent waters at the mouth yielded an average conversion factor of 1.94, while the most turbid headwaters yield an average conversion factor of 1.06. Overall, a clear trend was obvious along the transect which provided an almost linear match with total suspended solids. At the Susquehanna River mouth in September 1990, a series of 24 Secchi depth and light attenuation coefficient readings were taken on a sunny afternoon. Both the Secchi disk and light sensor lines were carefully checked for accuracy, and six readings were made at each of four locations. Conversion factors ranged from 1.5 to 1.95 and averaged 1.71. This variation is not unusual. Megard and Berman (1989) noted conversion factor ranges from 0.86 to 2.07 in a very clear region of the Mediterranean Sea. The variations were induced primarily by water column algae and suspended solids. For the entire Sassafras River, the average of all conversion factors for 1989 was 1.54.

Total Suspended Solids, Chlorophyll *a*, and Light Attenuation: Upper Chesapeake Bay

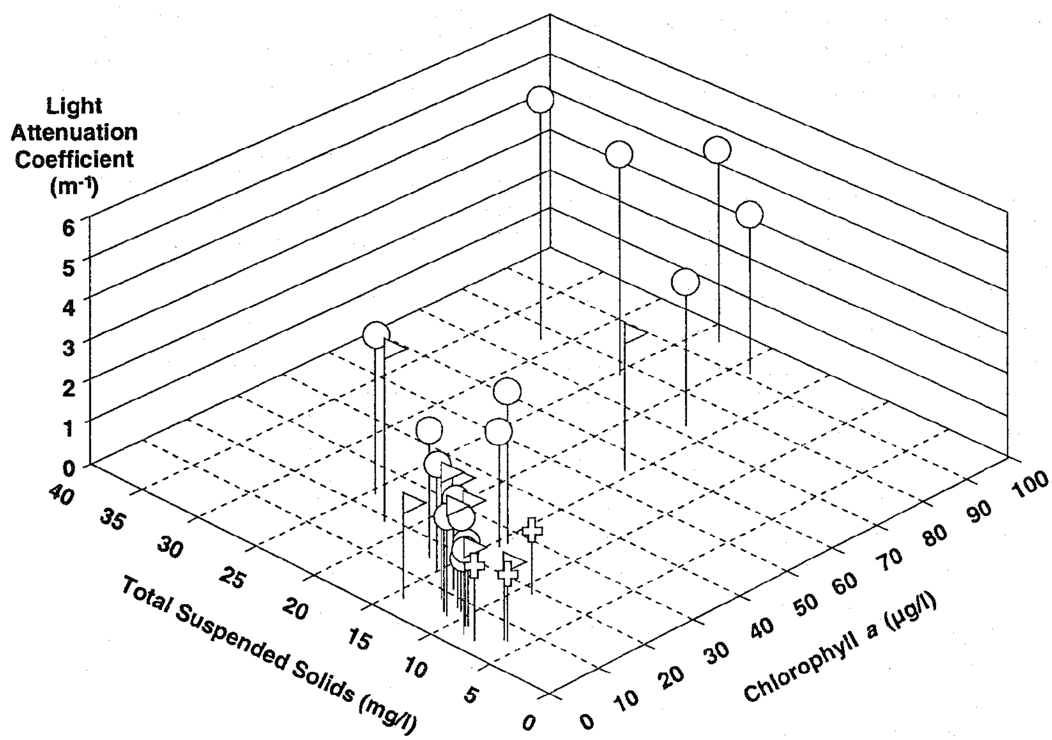

Figure V-12. Three-dimensional plot of April-October median light attenuation coefficient, total suspended solids, and chlorophyll *a* concentrations at the upper Chesapeake Bay stations for 1989. Stations are plotted separately with SAV status indicated. Plus = persistent SAV; flag = fluctuating SAV; circle = SAV absent.

Total Suspended Solids

Based on 1989 data, no persistent SAV sites existed where total suspended solids growing season median values were above 15 mg/l. The best sites averaged below 10 mg/l (Figures V-9 through V-11). Sites at the Susquehanna mouth, which were thriving from 1985 to 1988, lost half their biomass in 1989. While the 1989 data indicate that June was the worst month (total suspended solids >30 mg/l), the Susquehanna River was exceedingly turbid during the months of April and May. Data from late May 1989 showed total suspended solid levels of around 10 mg/l, indicating that the earlier, more turbid conditions were missed as sampling was not initiated until late May.

In the Sassafras River in 1989 (Figure V-10), the Sassafras Mouth (station 18) and Grove Point (station 17) sites had healthy *M. spicatum* and *P. crispus* populations with marginal *V. americana* transplant success. The upriver limits of SAV survival in the Sassafras River occurred at growing season median total suspended solid concentrations of 15 mg/l.

In the Elk River (Figure V-11), total suspended solid concentrations at the healthiest native SAV and transplant sites–Elk Neck (station 25) and Elk River mouth (station 19)–averaged 9 mg/l over the growing season. The maximum total suspended solids concentration at which SAV survived in the upper Chesapeake Bay and Susquehanna Flats was 16 mg/l, while levels below 10 mg/l strongly correlated with a higher abundance of persistent SAV.

Chlorophyll a

The Sassafras River best illustrates the impact of chlorophyll *a* on SAV populations in the upper Chesapeake Bay's tidal freshwater systems. For both 1988 (Figure V-13) and 1989 (Figure V-14), no persistent SAV populations survived where growing season median chlorophyll *a* levels rose above 15 µg/l, except at Ordinary Point (station 11 in Figure V-13) and Grove Neck (station 17 in Figure V-14). Transplants at Ordinary Point were planted during 1988 in a shallow, very well protected area which enhanced their survival. Although still present in 1989 (Figure V-14), the Ordinary Point transplants barely survived. From July through October the lowest chlorophyll *a* reading was 25.9 µg /l (there were only four chlorophyll *a* values in 1989). The transplants at Grove Neck also declined in 1989, leading to a complete loss of *V. americana* there. Transplants did fairly well at Grove Neck up to 1988. When the water quality declined in 1989, only *P. crispus* and *M. spicatum* survived. Because both species had already grown to the water surface when water quality began to deteriorate in April, they were less impacted by the in-

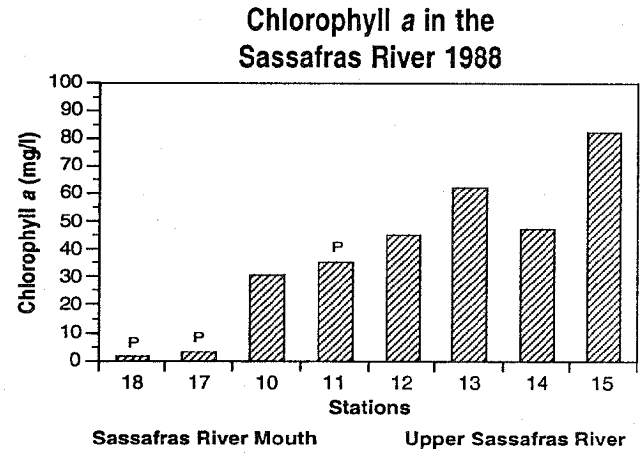

Figure V-13. Growing season 1988 median chlorophyll *a* concentrations from the Sassafras River mouth upriver. P=Persistent SAV; F=Fluctuating SAV; remaining sites were unvegetated.

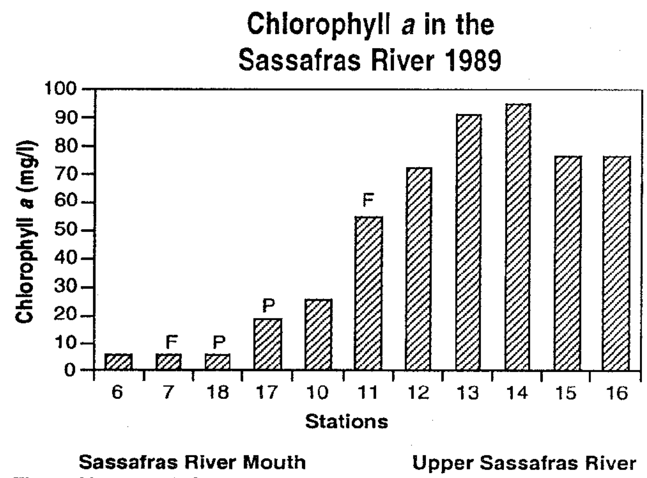

Figure V-14. April-October 1989 median chlorophyll *a* concentrations from the Sassafras River mouth upriver. P=Persistent SAV; F=Fluctuating SAV; remaining sites were unvegetated.

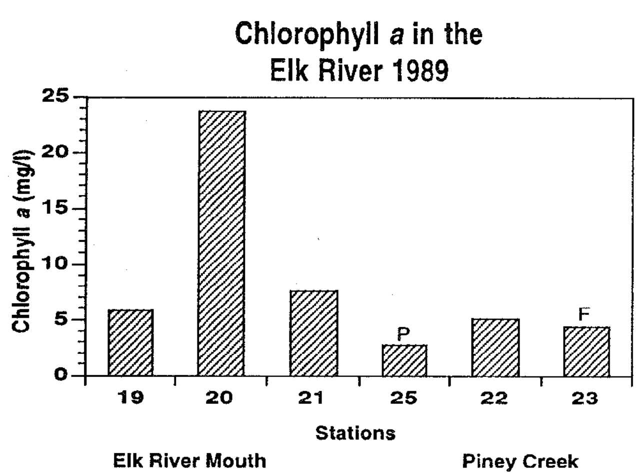

Figure V-15. April-October 1989 median chlorophyll *a* concentrations from the Elk River mouth upriver. P=Persistent SAV; F=Fluctuating SAV; remaining sites were unvegetated.

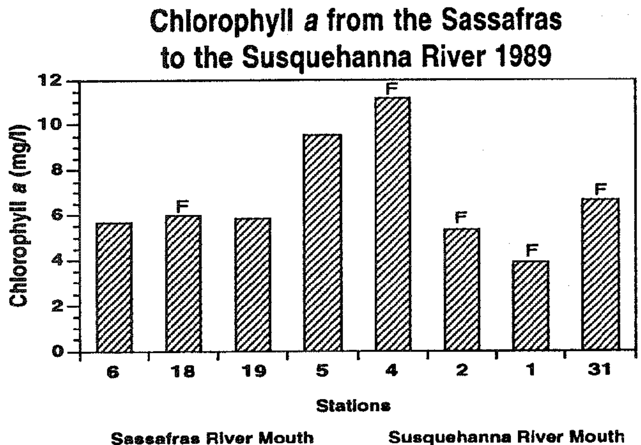

Figure V-16. April-October 1989 median chlorophyll *a* concentrations from the mouth of the Sassafras River through the Susquehanna Flats to the mouth of the Susquehanna River. P=Persistent SAV; F=Fluctuating SAV; remaining sites were unvegetated.

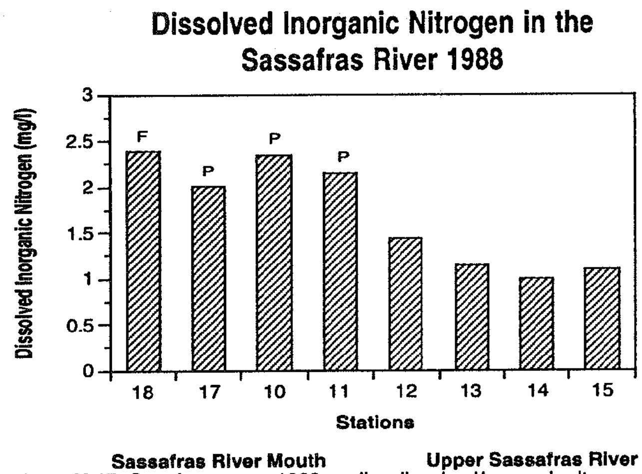

Figure V-17. Growing season 1988 median dissolved inorganic nitrogen concentrations from the Sassafras River mouth upriver. P=Persistent SAV; F=Fluctuating SAV; remaining sites were unvegetated.

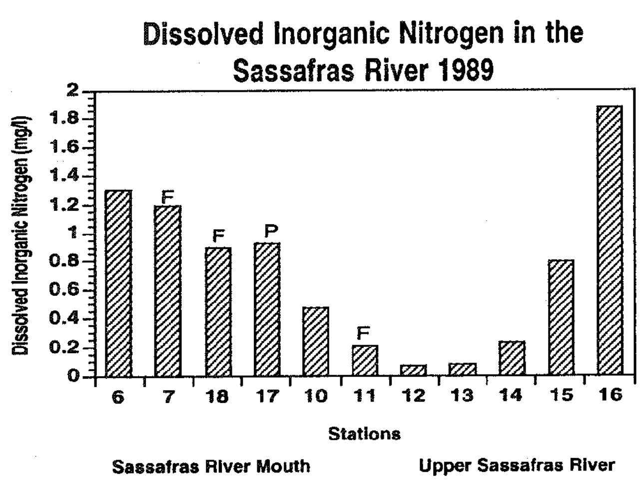

Figure V-18. Growing season 1989 median dissolved inorganic nitrogen concentrations from the Sassafras River mouth upriver. P=Persistent SAV; F=Fluctuating SAV; remaining sites were unvegetated.

creases in light attenuation and chlorophyll *a* and thus were able to survive.

In the Elk River, growing season median chlorophyll *a* concentrations were always below 15 µg/l except in Cabin John Creek (station 20) where no transplant plots have ever survived (Figure V-15). In the lower Susquehanna River, phytoplankton are unlikely to develop since the Conowingo Dam is a bottom discharge facility. Few or no actively growing phytoplankton are released into the river and the rate of flow is sufficiently swift that chlorophyll *a* levels greater than 15 µg/l do not occur until the middle of Susquehanna Flats (Figure V-16).

Dissolved Inorganic Nitrogen

The concentrations of nitrogen in the upper Chesapeake Bay study region appear to be less important than phosphorus in controlling chlorophyll *a* concentrations. If dissolved inorganic nitrogen concentrations (Figure V-17) are compared with chlorophyll *a* concentrations (Figure V-13), the trends with river distance are in opposite directions. This same pattern is noted in 1989 when dissolved inorganic nitrogen concentrations (Figure V-18) are compared with chlorophyll *a* (Figure V-14). High chlorophyll *a* concentrations in the upper reaches correspond to lower dissolved inorganic nitrogen levels of which nitrate is usually the largest component. Because chlorophyll *a* levels are highest when dissolved inorganic nitrogen concentrations are at their lowest, it is not plausible that phytoplankton levels are nitrogen limited. It seems that peak phytoplankton concentrations correspond with peak nitrogen uptake.

Figure V-19 demonstrates that while most healthy upper Bay SAV populations in 1988 occurred where dissolved inorganic phosphorus (unfiltered) growing season median values were below 0.02 mg/l, nitrate and ammonium growing season median levels ranged up to 2.2 mg/l. At the Sassafras River stations during 1989, dissolved inorganic nitrogen concentrations are more tightly clustered (Figure V-20), but SAV are distributed over a broader range of dissolved inorganic nitrogen levels (rather than dissolved inorganic phosphorus). Therefore, in the tidal fresh and oligohaline waters of the upper Chesapeake Bay, nitrogen species do not appear to be important in controlling phytoplankton concentrations.

Dissolved Inorganic Phosphorus

During 1988, growing season median unfiltered dissolved inorganic phosphorus concentrations ranged from 0.007 to 0.046 mg/l in the Sassafras River (Figure V-21) and from 0.006 to 0.026 mg/l along the transect from the Sassafras

Nitrate and Ammonium, Dissolved Inorganic Phosphorus, and Light Attenuation: Upper Chesapeake Bay

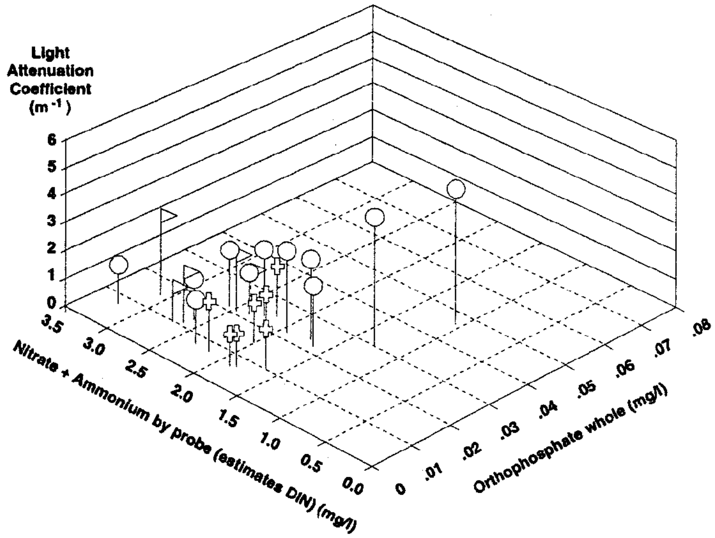

Figure V- 19. Three-dimensional plot of April-October median light attenuation coefficient, nitrate and ammonium, and dissolved inorganic phosphorus (unfiltered) concentrations at upper Chesapeake Bay stations in 1988. Stations are plotted separately with SAV status indicated. Plus = persistent SAV; flag = fluctuating SAV; circle = SAV absent.

Dissolved Inorganic Nitrogen, Dissolved Inorganic Phosphorus, and Light Attenuation: Sassafras River

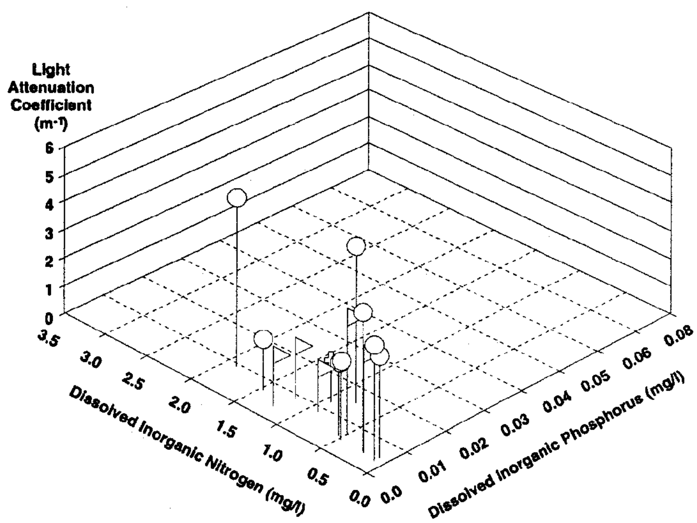

Figure V- 20. Three-dimensional plot of April-October median light attenuation coefficient, dissolved inorganic nitrogen, and dissolved inorganic phosphorus concentrations at the Sassafras River stations in 1989. Stations are plotted separately with SAV status indicated. Plus = persistent SAV; flag = fluctuating SAV; circle = SAV absent.

Table V-2. SAV habitat requirements for tidal fresh and oligohaline habits in the upper Chesapeake Bay.

Parameter	Habitat Requirement
Light attenuation coefficient	<2 m^{-1}
Total suspended solids	<15 mg/l
Chlorophyll *a*	<15 µg/l
Dissolved inorganic phosphorus	<0.02 mg/l
Dissolved inorganic nitrogen	No limit set

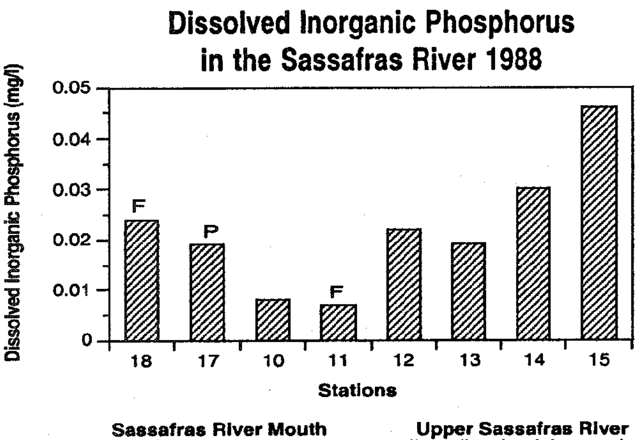

Figure V-21. Growing season 1988 median dissolved inorganic phosphorus (unfiltered) concentrations from the Sassafras River mouth upriver. P=Persistent SAV; F=Fluctuating SAV; remaining sites were unvegetated.

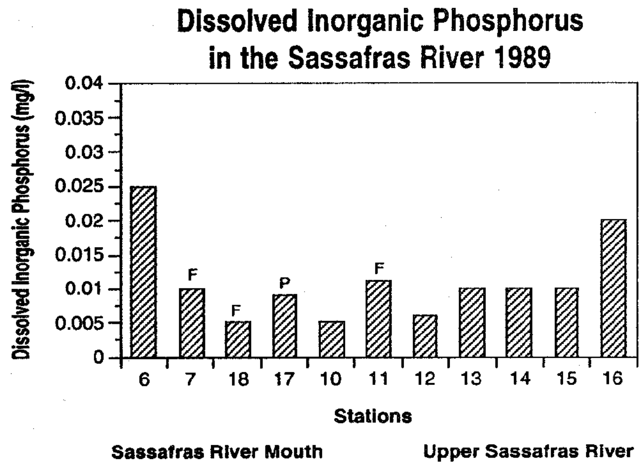

Figure V-23. April-October 1989 median dissolved inorganic phosphorus concentrations from the Sassafras River mouth upriver. P=Persistent SAV; F=Fluctuating SAV; remaining sites were unvegetated.

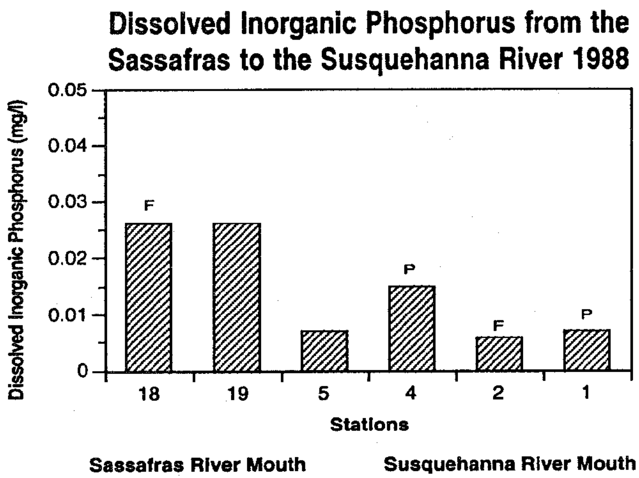

Figure V-22. Growing season 1988 median dissolved inorganic phosphorus (unfiltered) concentrations along a transect of stations from the mouth of the Sassafras River through the Susquehanna Flats to the mouth of the Susquehanna River. P=Persistent SAV; F=Fluctuating SAV; remaining sites were unvegetated.

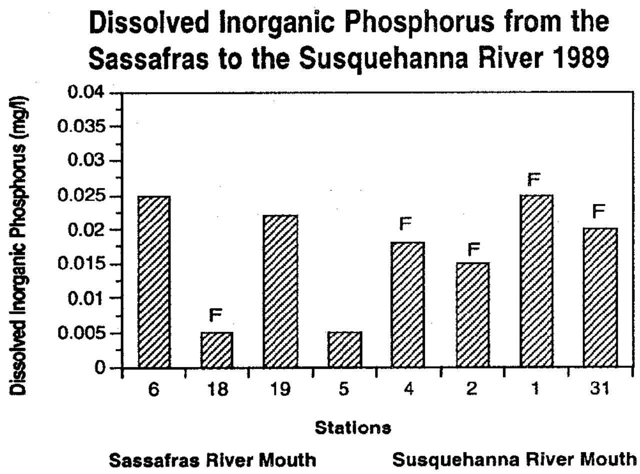

Figure V-24. April-October 1989 median dissolved inorganic phosphorus concentrations along a transect of stations from the mouth of the Sassafras River through the Susquehanna Flats to the mouth of the Susquehanna River. P=Persistent SAV; F=Fluctuating SAV; remaining sites were unvegetated.

River to the mouth of the Susquehanna River (Figure V-22). Growing season median values during 1988 were higher than 1989. This difference is possibly due to the fact that samples were unfiltered during 1988 and filtered in 1989. In 1989, growing season median dissolved inorganic phosphorus concentrations ranged from 0.005 mg/l to 0.025 mg/l in the Sassafras River (Figure V-23) and from 0.005 to 0.025 mg/l along the transect from the Sassafras River to the mouth of the Susquehanna River (Figure V-24).

Lower dissolved inorganic phosphorus readings correspond to the presence of SAV, although the correspondence in the upper Bay waters is not so strong as with light attenuation coefficient, total suspended solids, and chlorophyll *a*. In the upper Bay, SAV declined in 1989 after two drought years during which *V. americana* began to recolonize many areas both vegetatively and from seed. While this loss of SAV may be more easily correlated with light attenuation, the majority of healthy SAV sites had growing season median dissolved inorganic phosphorus concentrations <0.02 mg/l during 1988 (Figures V-19, V-21 and V-22) and dissolved inorganic phosphorus concentrations below 0.01 mg/l during 1989 (Figures V-20, V-23 and V-24).

Sediments

Sites with healthy SAV tended to have similar substrates. At the sites listed in Table V-1, where native SAV populations exist or where transplants survived, the sediments consisted of at least 6% silt, no more than 90% sand, and between 1–5.3% organic matter. Log Pond was an anomalous case, supporting a robust SAV population with 7.5% organic matter in the lower sediment strata (5–15 cm). At several locations, persistent SAV beds were noted in similar circumstances where sandier sediments overlaid more finely textured substrates.

Barko and Smart (1986) described optimum organic matter and silt fractions for several SAV species and noted a decline in productivity when sediments contain more than 5% organic matter. Since *V. americana* and other SAV species have been described growing in sediments ranging from pebbles to peat (Hunt 1963; Korschagen and Green 1985), an optimum substrate combination seems to be necessary in the upper Chesapeake Bay to give the plants the edge to survive unfavorable ambient water quality conditions. This edge might be achieved by increasing cation exchange capacity, anchoring ability, or ease of stolon penetration. Under more optimum water quality conditions, the plants would likely survive and grow in a greater diversity of substrates.

Summary and Conclusions

SAV habitat requirements were established (Table V-2) based on correspondences between the distributions of SAV, SAV transplant success, and growing season medians of water quality in tidal fresh and oligohaline waters of the upper Chesapeake Bay. In summary:

1) SAV beds found at or below 1.0 m mean tidal depth will begin to decline when growing season median Secchi depths are <1.0 m, or growing season median light attenuation coefficient values rise above 2.0 m^{-1} (during periods of SAV expansion, Secchi depths were always above 1.2 m).
2) SAV declines when total suspended solids growing season median concentrations rise above 15 mg/l. At sites where total suspended solids concentrations average above 20 mg/l, SAV are not found. Generally, total suspended solid levels below 10 mg/l are required to support persistent SAV growth, revegetation, and expansion.
3) No persistent SAV populations have been noted when chlorophyll *a* growing season median concentrations rise above 15 µg/l.
4) Based on 1988 and 1989 data, the observed range of growing season median concentrations of dissolved inorganic nitrogen (1.0 to 2.5 mg/l) do not appear to limit SAV growth and survival in this region.
5) Dissolved inorganic phosphorus growing season median concentrations above 0.01 mg/l were deleterious to transplants and to young seedlings in marginal beds. While certain well-established beds tolerated growing season median concentrations up to 0.02 mg/l, SAV declined at growing season median concentrations above this value.
6) With the existing poor water quality conditions in the upper Chesapeake Bay, SAV appear to be confined to a narrower range of sediments than they might otherwise tolerate. Sandy loams or silts with at least 6% silt and from 1–5% organic matter promote optimum SAV growth and survival.

Upper Potomac River

Habitat requirements for SAV in the tidal fresh Potomac River and the oligohaline transition zone of the Potomac Estuary were developed by analyzing existing water quality data collected before and during reestablishment of SAV. These data were correlated with the environmental conditions that supported the reestablishment and continued expansion in coverage of three key species–*H. verticillata, M. spicatum*, and *V. americana*. These three species along with *C. demersum* are the dominant species in the tidal river and transition zone.

Although two of these species are exotics (*H. verticillata* and *M. spicatum*), it appears that these species are also indicators of suitable environmental conditions for SAV in tidal fresh and oligohaline habitats of Chesapeake Bay. The water quality data analyzed here were collected by several agencies for different objectives including characterization of trends and development of a better understanding of factors affecting the distribution and density of SAV. The natural revegetation of the Potomac River as a result of improvements in water quality since the early 1970s has provided a "natural laboratory" for development of habitat requirements for tidal fresh and oligohaline Chesapeake Bay SAV species.

Study Area

The tidal Potomac River and Estuary extends 183 km from the river's mouth to Chain Bridge in Washington, DC. This study focuses only on the tidal fresh reach of the river between Chain Bridge and Quantico, Va. and the oligohaline reach of the transition zone of the Potomac Estuary between Quantico and Maryland Point. For the purposes of this report, the tidal freshwater reach has been further subdivided into the upper tidal river (Washington, DC to Marshall Hall) and the lower tidal river (Marshall Hall to Quantico) (Figure V-25).

Methods

Distribution Surveys

Between 1978 and 1981, the USGS conducted an initial survey of SAV in the tidal Potomac River and Estuary to establish baseline distribution and density. Permanent transects were established in the tidal river, transition zone, and estuary (Table V-3)(Carter *et al.* 1985a). The transects relevant to this study are in the Piscataway-Mattawoman Creeks, the Nanjemoy Creek-Port Tobacco River, the Aquia-Potomac Creeks, and the Gunston Cove regions (Figure V-25). Additional transects were added to fill in sampling gaps including five transects in Washington, DC, sampled in 1978 but not in subsequent years. Data on vegetation and substrate composition were collected by seasonal sampling at stations along these transects using modified oyster tongs with blades welded across the teeth to facilitate biting into the sediment and collecting rooted plants (Paschal *et al.* 1982). Vegetation samples were identified at the species level, and wet volumes per grab for each species were taken as a measure of relative biomass. A total of 27,509 samples was collected along 256 different transects as part of this formal sampling program in the tidal Potomac River and Estuary.

Following the resurgence of SAV in the upper tidal Potomac River in 1983 (Carter and Rybicki 1986), the USGS began monitoring the distribution and abundance of plants in the tidal river on an annual basis and, less frequently, in the transition zone. This monitoring was done to follow the progress of revegetation and to provide distribution and density data for correlation with water quality data. Two general methods were adopted for monitoring–intensive shoreline surveys and sampling on permanent transects. Table V-3 summarizes the sampling program for 1983-1988.

Table V-3. Summary of shoreline and transect sampling in the tidal Potomac River and transition zone of the Potomac Estuary, 1983-1988. Transition zone includes only Quantico to Maryland Point.

Year	Shoreline Surveyed	Number of Transects Sampled	Biomass Measured
1983	Washington, DC to Quantico, VA	None	No
1984	Washington, DC to Quantico, VA, and Mallows Bay, MD	Tidal river: 69 Transition zone: 4	Yes
1985	Washington, DC to Quantico, VA, and Mallows Bay, MD	Tidal river: 62	Yes
1986	Washington, DC to Quantico, VA and Mallows Bay, MD	Tidal river: 62 Transition zone: 35	Yes
1987	Washington, DC to Maryland Point	Transition zone: 35	No
1988	Washington, DC to Maryland Point	Tidal river: 4 Transition zone: 35	No

Shoreline surveys were done by boat at low tide, using rakes to gather samples and check whether plants were rooted or floating. Beginning in 1984, percent cover and proportion of each species were estimated and referenced to 1 km square grids shown on the USGS 7-1/2-minute topographic and bathymetry maps. The ranges of percent cover used (<10%, 10%-40%, 40%-70%, and 70%-100%) were those used by Orth *et al.* (1979). Distribution information was transferred to small-scale maps for publication in a series of yearly USGS Open-File Reports (Rybicki *et al.* 1985, 1986, 1987, 1988; Rybicki and Schening 1990; Carter *et al.* 1985b) and summarized by Orth *et al.* (1985, 1986, 1987, 1989) and Orth and Nowak (1990).

Permanent transects, established during 1978-1981, were supplemented with additional transects when necessary to provide more complete coverage. In the transition zone, only transects that had three or more species during 1978-1981 were resampled in 1984. Transect sampling methods are summarized in Open-File Reports published by the USGS for individual years (Rybicki *et al.* 1985, 1986, 1987, 1988; Carter *et al.* 1985b; Rybicki and Schening 1990).

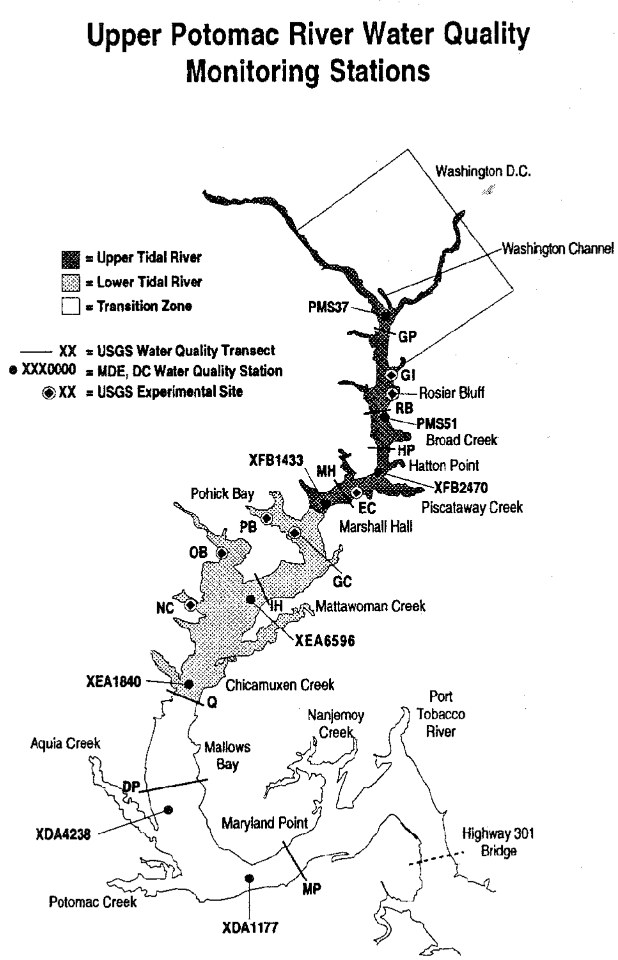

Figure V-25. Water quality monitoring stations and transects located in the upper Potomac River.

Transplant Experiments

Plugs, sprigs, and tubers of *V. americana* were transplanted from the Potomac Estuary to six sites in the tidal Potomac River during 1980-1983 (Carter and Rybicki 1985). Four of these sites—Goose Island (GI), Rosier Bluff (RB), Elodea Creek (EC), and Neabsco Creek (NC) (Figure V-25)—were used as intensive study sites. Tubers and sprigs were planted by hand at water depths between 0.5 and 1.0 m. Plugs with three to six plants each were planted in shallow trenches. Hardware cloth and wood exclosures were placed around selected transplant plots to assess the affect of grazers on survival. Water transparency was measured with a Secchi disk. Photosynthetically active radiation was measured during 1981 with a LICOR 185B Quantum Radiometer-photometer equipped with an underwater sensor. Light energy in $\mu E\ m^{-2}s^{-1}$ was measured above the water surface, just below the water surface, and at 20 cm increments below the water surface. Sediment type was determined for all sites. To compare plant density and rhizome development, cores were taken in 1981 from the transplanted plot at Rosier Bluff, a natural bed of *V. americana* in the Washington Channel, and from two natural beds of *V. americana* in the oligohaline transition zone.

Biomass Determinations

Biomass sampling techniques and locations varied from year to year as the coverage and density of SAV increased. In general, samples were placed in mesh bags and hung on lines to air dry. They were then dried in ovens at 105-110 °C, and the dry weight (in grams per grab sample) or biomass (in grams dry weight/m^2) of each species was determined.

Growth Experiments

Although revegetation by SAV has occurred in the main river and shallow embayments on the Maryland side, SAV has not returned to the shallow Pohick Bay (PB) and Occoquan Bay (OB) located on the Virginia side of the lower tidal river (Figure V-25). To ascertain whether the lack of SAV was solely a result of poor light penetration, *V. americana* was planted in exclosures in shallow, unvegetated embayments PB (1987-1989) and OB (1989 only), with light supplied to the experimental cages by swimming pool lights during daylight hours.

Water Quality Monitoring

During 1979-1989, the USGS made numerous water quality measurements in the tidal river and transition zone to help determine the factors that were controlling SAV revegetation and the effects that reestablishment of SAV might have on water quality. Samples were collected at irregular intervals during the growing season and the number of stations was variable. Most of the data were collected in water ≤3 m in depth. Water quality parameters included total Kjeldahl nitrogen, nitrate plus nitrite, dissolved inorganic phosphorus, total soluble phosphorus, total ammonia, total phosphorus, light attenuation coefficient, Secchi depth, total suspended solids, and chlorophyll *a*–the nutrient parameters were measured only in 1985.

During the 1985-1986 growing seasons, USGS measured light attenuation coefficient and concentrations of chlorophyll *a* and total suspended solids every two weeks in the vegetated upper tidal river, the unvegetated lower tidal river, and the vegetated oligohaline transition zone, to determine whether changing light availability was responsible for the discontinuous distribution of vegetation in the tidal river (Carter and Rybicki 1990). Incident and underwater irradiance were measured with a portable LICOR submersible scanning spectroradiometer. Secchi depth was measured simultaneously. In 1985, measurements were made at six stations (two in each reach) and at 12 stations (four in each reach) in 1986 (Figure V-25). Stations were ≤3 m in depth and were located outside plant beds along the margin of the river. In addition, stations were located in two shallow embayments, Pohick Bay and Occoquan Bay, in 1986 (Figure V-25).

Water quality data sets, available for the tidal Potomac River and oligohaline transition zone of the Potomac Estuary for 1979-1989, were obtained from several different sources for this analysis. USGS data came from the USGS Potomac Estuary Study, 1979-1983 (excluding 1982). This study was intended to provide a comprehensive look at water quality in the tidal Potomac River and Estuary (Callender *et al.* 1984). Data collection was conducted at fixed stations along the length of the river from Chain Bridge to Maryland Point (Figure V-25 and Table V-4) and during longitudinal cruises. At some stations, depth-integrated vertical samples were collected at more than one location in the cross section and composited. At other stations, or at different sampling times, only near-surface mid-channel samples were collected. The data were divided into two sets for the trend analysis-cross-sectional composites and near-surface channel samples. Sampling was monthly or weekly during 1979-1981 depending on the station; however, sampling consisted of several longitudinal sampling cruises in 1983. Water quality parameters included Secchi depth and concentrations of dissolved ammonia, total ammonia, nitrate plus nitrite, total Kjeldahl nitrogen, total phosphorus, dissolved inorganic phosphorus, total soluble phosphorus, total suspended solids, and chlorophyll *a*. Data are summarized in Blanchard *et al.* (1982a, 1982b), Blanchard and Hahl (1981), Coupe and Webb (1983), and Woodward *et al.* (1984).

Other data sets were acquired either through the Metropolitan Washington Council of Governments, which coordinates and provides database management for all monitoring data collected in the Potomac River and publishes reports on the water quality of the Potomac River (Metropolitan Washington Council of Governments 1983, 1984, 1985, 1986, 1990), or directly through the collection agencies. These include data sets from the following agencies:

The Maryland Department of the Environment (MDE), 1983-1989: MDE sampled every 2 weeks during the growing season (April-October) at fixed stations along the mainstem of the Potomac from Hatton Point to Maryland Point (Figure V-25 and Table V-4). Sampling was done in the mid-channel at depths of 0.3 m and 5 m and near the bottom. Only the samples collected near the surface (0.3 m) were used in this analysis. Parameters included total ammonia, nitrate plus nitrite, total Kjeldahl nitrogen, total phosphorus, total orthophosphorus, total suspended solids, chlorophyll *a*, and Secchi depth.

The District of Columbia Department of Consumer and Regulatory Affairs (DC), 1983-1988: these samples were collected monthly at fixed stations, two of which were used in this analysis (Figure V-25 and Table V-4). The samples were collected at the surface of the river channel. Water quality parameters included dissolved ammonia, nitrate plus nitrite, total Kjeldahl nitrogen, total phosphorus, dissolved inorganic phosphorus, total dissolved phosphorus, total suspended solids, chlorophyll *a*, and Secchi depth.

Appendix B summarizes the analytical methods used by each agency for each of the water quality parameters and comments on their compatibility. The major difficulties of comparing diverse data sets include: 1) differences in sample collection methods (depth-integrated samples, composited samples, surface samples, mid-channel versus nearshore samples); 2) differences in sample treatment and preservation (filtered versus unfiltered nutrient samples); 3) differences in actual parameters measured and methods of analysis (dissolved versus total); 4) differences in detection limits for parameters; and, 5) changes in detection limits and methods over the period of record.

Table V-4. Water quality monitoring stations used for the water quality analyses of the tidal Potomac River and transition zone of the Potomac Estuary.

Station Name	Latitude	Longitude
Upper Tidal River: salinity 0-0.5 ppt		
Geisboro Point (GP)	38°50'39"	77°01'26"
USGS 385039077015800	38°49'18"	77°01'53
Rosier Bluff (RB)		
USGS 384605077015800	38°46'05"	77°01'58"
USGS Wetland Studies site RB	38°46'31"	77°01'46"
DC PM551	38°46'12"	77°01'54"
Hatton Point (HP)		
USGS 384318077020300	38°43'18"	77°02'03"
MDE XFB2470	38°42'23"	77°02'57"
Marshall Hall (MH)		
USGS384136077054500	38°41'36"	77°05'46"
USGS Wetland Studies site EC	38°41'30"	77°04'47"
MDE XFB1433	38°41'26"	77°06'31"
Lower Tidal River: salinity 0-3 ppt		
Gunston Cover (GC)		
USGS Wetland Studies site GC	38°40'02"	77°08'10"
Pohick Bay (PB)		
USGS Wetland Studies site PB	38°40'37"	77°09'53"
Occoquan Bay (OB)		
USGS Wetland Studies site OB	38°38'24"	77°13'12"
Indian Head (IH)		
USGS 01655480	38°36'03"	77°10'56"
USGS Wetland Studies site MN	38°33'39"	77°12'35"
MDE XEA6596	38°36'29"	77°10'27"
Quantico (Q)		
USGS 01658710	38°31'12"	77°17'08"
USGS Wetland Studies site MN	38°33'47"	77°12'35"
MDE XEA1840	38°31'47"	77°15'56"
Oligohaline Transition Zone: salinity 0-5-7 ppt		
Douglas Point (DP)		
USGS 382640077159900	38°26'40"	77°15'19"
USGS Weltand Studies site WB	38°25'54"	77°15'55"
MDE XDA4238	38°24'12"	77°16'10"
Maryland Point (MP)		
USGS 382233077102000	38°22'33"	77°10'20"
MDE XDA1177	38°21'07"	77°12'17"

Note: USGS = U.S. Geological Survey; MDE = Maryland Department of the Environment; DC = District of Columbia Department of Consumer Regulatory Affairs; VSWCB = Virginia State Water Control Board.

Water quality data are discussed by both station and reach (upper tidal river, lower tidal river, transition zone). Station data were collected primarily by USGS, MDE, and DC. Reach data were collected primarily by the USGS in conjunction with various experiments and monitoring programs described previously. Stations located in the upper tidal river reach include Geisboro Point (GP), Rosier Bluff (RB), Hatton Point (HP), and Marshall Hall (MH) (Figure V-25, Table V-4). Stations located in the lower tidal river reach include Indian Head (IH) and Quantico (Q). The oligohaline transition zone reach begins below Quantico and includes Douglas Point (DP) and Maryland Point (MP).

Growing season median values were calculated for all water quality parameters for 1980-1989. Median dissolved inorganic nitrogen was calculated by adding median nitrate plus nitrite to median dissolved ammonia (DC data) or median total ammonia (USGS and MDE data). For comparison purposes, median values for 1980, 1983, 1986, and 1989 are plotted for all stations by year. The 1980 data reflect conditions in the tidal river and transition zone before the plants resurgence. The 1983 data characterize water quality conditions when SAV grew back in the upper tidal river. Data from 1986 show water quality when vegetation in the upper tidal river was at its most extensive and the plants had begun to spread into the lower tidal river. The 1989 data complete the data set and show the status of water quality when plant populations increased in the lower tidal river and declined in the upper tidal river. Data from three stations—Hatton Point, Indian Head, and Douglas Point—were used for plots showing each parameter for all years when data were available. Water quality data were compared with SAV coverage in order to establish the SAV habitat requirements. Information on relative SAV coverage at water quality stations was taken from USGS survey data and aerial photographs. Actual coverage within a 2.5 km reach on either side of each station was acquired from the Chesapeake Bay Program's SAV Geographical Information Systems data base for 1984-1987 and 1989. Coverage for 1983 was estimated from USGS field notes and observations; coverage for 1988 was estimated from aerial photographs.

Trend Analysis

The nonparametric Seasonal Kendall test (Hirsch *et al.* 1982; Hirsch and Slack 1984) was used to examine the water quality trends in the upper Potomac River during 1980-1989. This time period corresponds with the reestablishment of SAV in the Potomac River. The trend is a linear, monotonic change in value over the period of the data. The Seasonal Kendall test accounts for the seasonal variation in water quality by dividing the data into seasons or months and testing each month's values for trends. A trend and level of significance are then calculated for all months. For periods over ten years, the level of significance of the test is adjusted for serial correlation among the months.

For this report, each data set was divided into seven calendar months (April through October). For each station and parameter, one nonmissing value was randomly selected for each month. 'Less than detection limit' values for each parameter were set to half the largest detection level. Results indicate whether the parameter increased or decreased over the period of the test or if there were no trends detected. Failure to detect a trend may be the result of missing data or the absence of a trend. Trends are only reported if the level of significance is 0.05. The following two types of data were tested: 1) those measured in the main channel at a depth of 1 m or less; and, 2) cross-section average values. All data collected by MDE and DC, and some data collected by USGS, comprise the first type. The remaining USGS data comprise the second type.

Trend tests were run on each of the following data sets: 1) USGS, 2) DC, 3) MDE, and 4) combined USGS, DC, and MDE. The combined data sets included only surface channel data. USGS data for 1983 were not used. Trends for the combined data sets are reported for those stations and parameters for which there are both USGS and either DC or MDE data.

Results

Distribution Surveys

Figure V-26 summarizes SAV distribution in the upper Potomac River for 1980, 1983, 1986, and 1989. Figure V-27 shows SAV distribution in the tidal Potomac River in 1916, suggesting the extent of SAV revegetation possible in this reach of the river. Today's channel, however, is probably wider than that in 1916. The 1979-1981 survey (Figures V-26 and V-28) showed that vegetation was extremely sparse in the tidal Potomac River. Most of the small isolated patches of SAV found in an intensive shoreline survey were in isolated or protected environments in tributaries rather than along the mainstem of the Potomac River (Haramis and Carter 1983; Carter *et al.* 1985a). A variety of SAV species was found on transects in the transition zone. Table V-5 lists species found during the survey.

Following the resurgence of plants in the upper tidal river, fifteen species of SAV were collected in the tidal Potomac River and transition zones of the Potomac Estuary from

Table V-5. List of SAV species found in the tidal Potomac River and oligohaline transition zone of the Potomac Estuary: 1978-1981 and 1983-1989.

Nitella flexilis	*Potamogeton pusillus*	*Hydrilla verticillata*
Chara braunii	*Zannichellia palustris*	*Elodea canadensis*
Chara zeylanica	*Najas guadalupensis*	*Egeria densa*
Potamogeton perfoliatus	*Najas minor*	*Ceratophyllum demersum*
Potamogeton pectinatus	*Najas gracillima*	*Myriophyllum spicatum*
Potamogeton crispus	*Vallisneria americana*	*Heteranthera dubia*

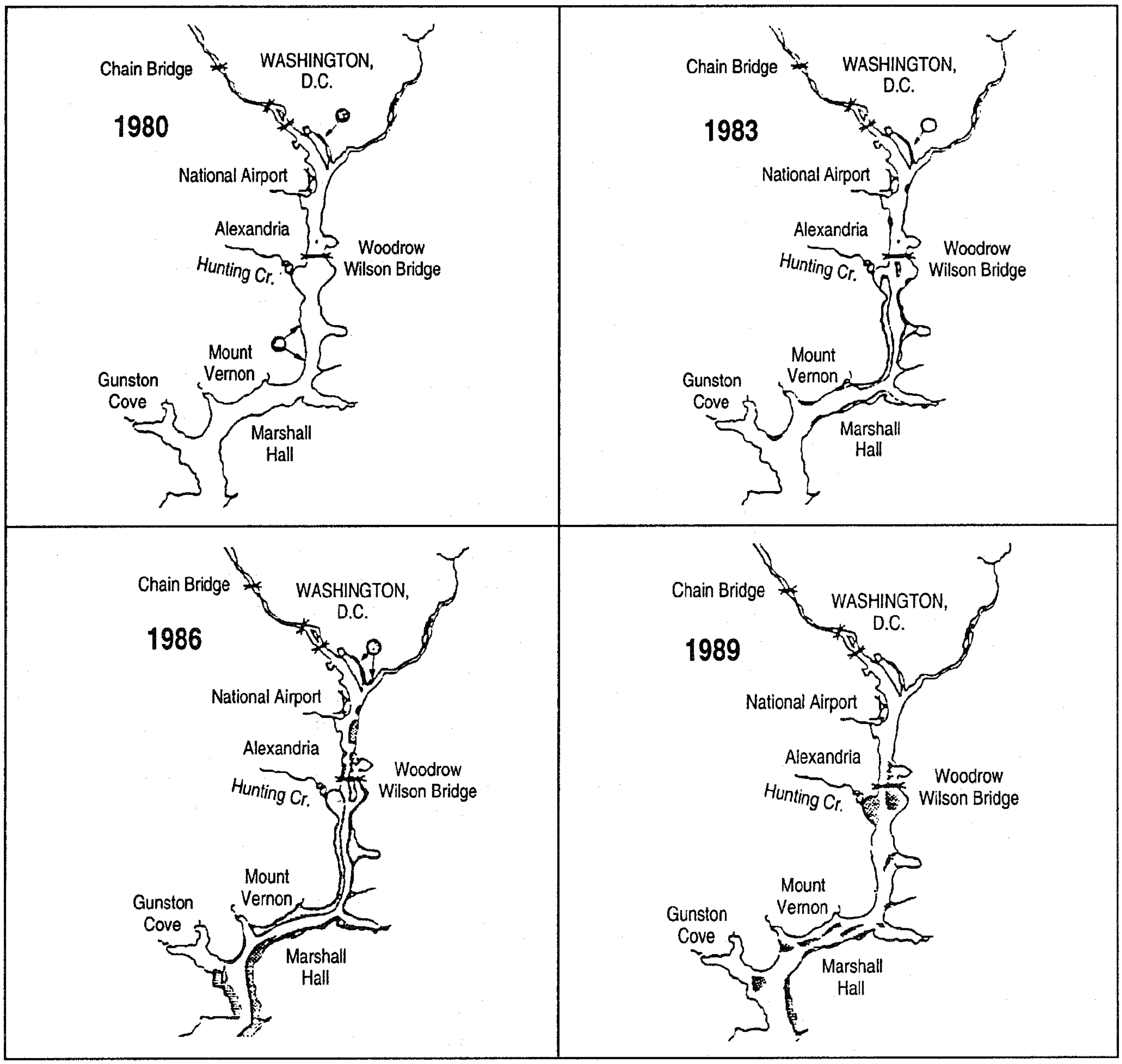

Figure V-26. Distribution of SAV (■) in the upper Potomac River during the 1980's. Modified from Carter and Rybicki 1986.

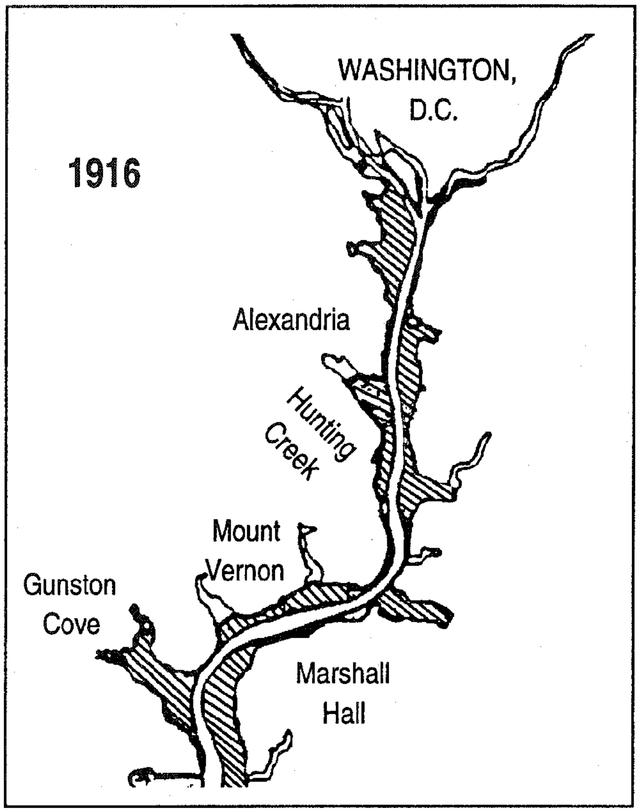

Figure V-27. Distribution of SAV (▧)in the upper Potomac River in 1916 (Cumming *et al.* 1916).

1983-1989 (Carter and Rybicki 1986) (Table V-5). The only new species identified in 1983 were *H. dubia*, *Najas minor*, and *N. flexilis*. The plant distribution was extremely patchy during 1983, except in the Alexandria area where *H. verticillata* was the dominant species. In subsequent years, however, SAV became increasingly dense (Figures V-28 through V-30). Plant populations stabilized in the upper tidal river (Geisboro Point, Rosier Bluff, Hatton Point, and Marshall Hall) in 1986 and 1987, with *H. verticillata* the dominant species throughout the reach. In 1988, plant area decreased, largely due to the disappearance of *H. verticillata* from the back of shallow coves (Piscataway Creek and Broad Creek) and from the deeper fringes of the plant beds. In 1989, there was a dramatic reduction in the *H. verticillata* population in the upper tidal river (Figures V-28 and V-29).

By 1986, SAV had spread below Marshall Hall into the lower tidal river (Indian Head and Quantico) (Figures V-28 and V-30). The distribution was patchy at first, but density increased during 1986 and 1989 as plants spread down river and into sites ≤2 m in depth. During the same period, *H. verticillata* was rapidly becoming the dominant species in this reach of the river as well.

Although confined to the shallow shoreline margins, SAV was present in the transition zone (Douglas Point, Maryland Point) during 1978-1981. These plants persisted in 1983-1989, becoming more dense and widespread between Quantico and Maryland Point (Figures V-28 and V-30). There was more SAV on the Maryland side of the river, growing discontinuously in shallow coves from Chicamuxen Creek south around Maryland Point. East of Maryland Point, the band of vegetation was relatively continuous and consistent from year-to-year.

Season Determination

After ten years of field observations, the basic phenological patterns of the three key species in the tidal Potomac River are fairly well understood. The onset of growth and germination depends on water and substrate temperature and thus varies from year to year. In general, the growing season in the tidal river and transition zone begins in April and ends with senescence in late October. *M. spicatum* is the first plant to grow and reach the water's surface. It sprouts from last year's root stocks and stems utilizing stored structural carbohydrate when water temperatures are about 12-13 °C usually reaching the surface within three weeks. *V. americana* germinates from overwintering tubers when the water temperature is 13 to 15 °C. *H. verticillata* tubers and turions do not sprout until the sediment and water temperatures are about 15 °C. All three plants grow more rapidly as water temperatures rise. None are limited by the maximum water temperatures (approximately 30 °C) in the tidal river or transition zone and continue to photosynthesize until the end of October.

Transplant Experiments

In 1980 and 1981, transplants were successful only when protected by full exclosures that prevented grazing (Carter and Rybicki 1985). Plants at Rosier Bluff and Elodea Cove, protected during the first year, were permanently established despite grazing in subsequent years, however, there was little or no expansion of these beds until 1983. The mean light attenuation coefficient at these sites was <2.7 m^{-1} with average 1% light level at a depth of 1.6-1.7 m. Plants were never permanently established at Goose Island or at Neabsco Creek where light penetration was poor with the average 1% light level at 1.4 m and 1.0 m, respectively, and a mean light attenuation ≥2.7 m^{-1}. In 1983, mean Secchi depth in the upper tidal river increased significantly compared with 1978-1981 (Table V-6) and both protected and unprotected transplants survived (Carter and Rybicki 1985). The results from the transplant experiments confirm that environmental conditions in the tidal river prior to 1983

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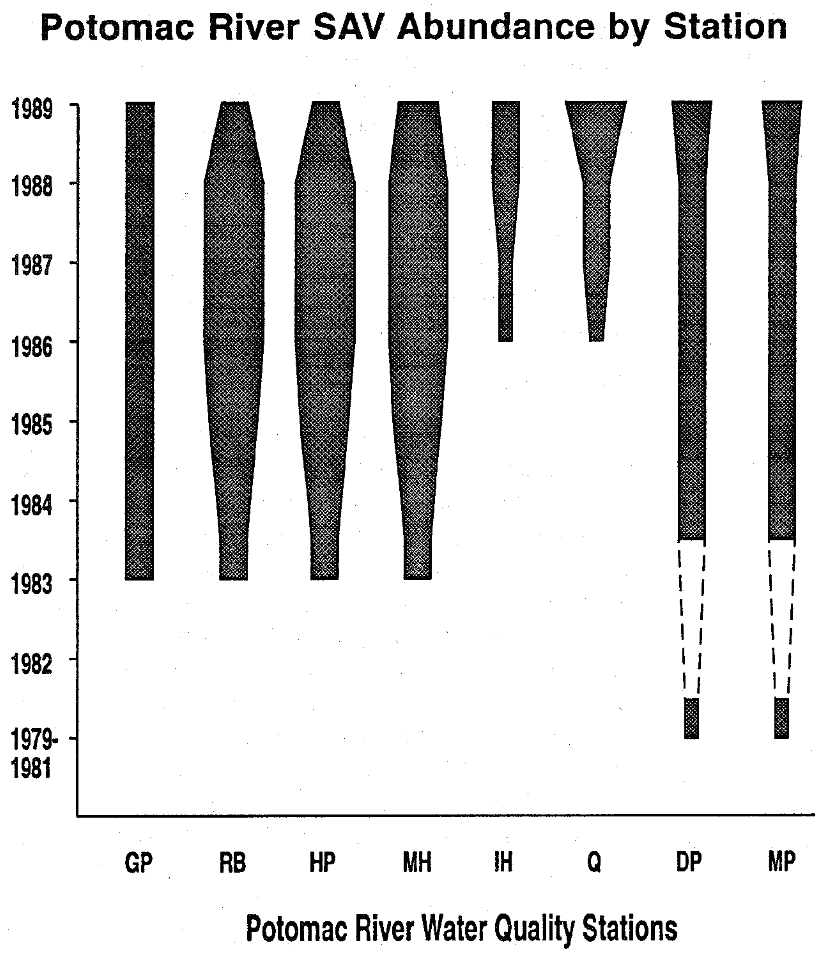

Figure V-28. Trends in SAV in the tidal Potomac River and transition zone of the Potomac Estuary, 1979-1989. Line width is proportional to density with the smallest width indicating a few small patches of vegetation and the largest width indicating dense coverage of all shallow sites. See Table V-3 for full station names.

were only marginally suitable for the establishment of vegetation because of high light attenuation and grazing.

Growth Experiments

The results of the light/transplant studies in Pohick and Occoquan bays show that light was the primary factor controlling the growth and survival of SAV at both sites. At Pohick Bay in 1987 and 1988, the only SAV transplants surviving through the end of the summer were in the experimental cages to which artificial light was added. In 1987, light attenuation coefficients varied from 2.4 m^{-1} (in June) to 8.8 m^{-1} (in August).

In 1989, the only year in which both Occoquan and Pohick bays were studied, the biomass in the experimental cages at both sites was significantly greater than that in the unlit control cages. Biomass in the experimental cages in Pohick Bay averaged 65 g dry weight compared to an average of 2 g dry weight in the controls. Biomass in the experimental cages in Occoquan Bay averaged 63 g dry weight compared with 6 g dry weight in the controls.

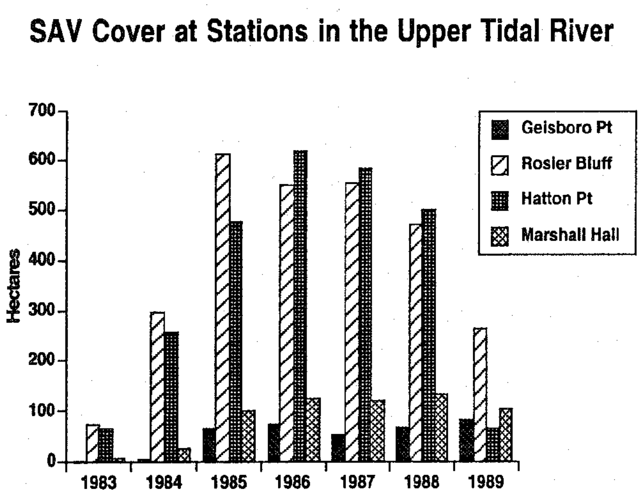

Figure V-29. SAV cover at stations in the upper tidal Potomac River from 1983-1989.

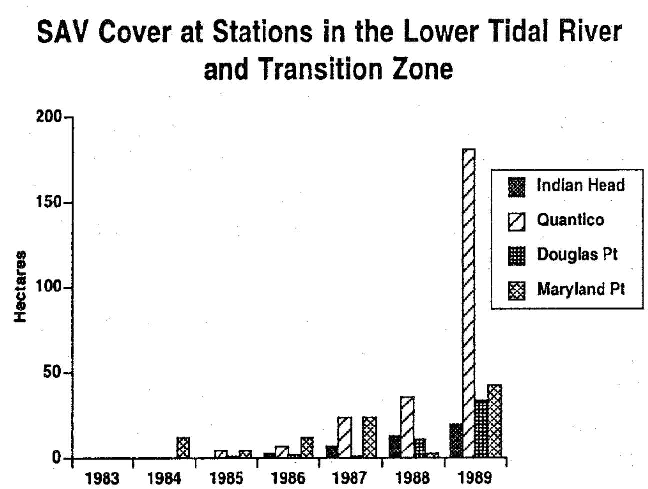

Figure V-30. SAV cover at stations in the lower tidal Potomac River and the transition zone of the Potomac Estuary from 1983-1989.

Table V-6. Summary of mean Secchi depths in the upper tidal Potomac River, the lower tidal Potomac River, and the transition zone of the Potomac Estuary (1979-1981, 1983, 1985, and 1986).

	Mean Secchi Depth			
Location	1979-1981	1983	1985	1986
Upper Tidal River	0.53 (1.7, 117) (a)	0.86 (4.4, 50) (c)	0.89 (3.3, 85) (c)	0.83 (3.3, 76) (c)
Lower Tidal River	0.43 (0.87, 142) (b)	0.50 (5.1, 13) (b) (d)	0.59 (1.9. 78) (d)	0.53 (1.5, 101) (d)
Transition Zone	0.45 (0.81, 229) (b)	n.d.	0.69 (2.8, 23) (a)	0.51 (2.8, 51) (b)

Data are presented as mean Secchi depth in m (standard error, number of samples). Column numbers designated by different letters are significantly different, $p < 0.001$; row numbers designated by different letters are significantly different, $p < 0.001$. Data from 1979-1981 include the entire transition zone from Quantico to the Route 301 Bridge, whereas data from 1985 and 1986 include only the oligohaline transition zone.

Water Quality Parameters

Tables V-7 through V-9 give the results of the trend analyses and are discussed by parameter in the following text. No trends were detected in any of the selected parameters in the 1983-1989 DC data for Geisboro Point and Rosier Bluff.

Secchi Depth

Figures V-31 through V-34 show growing season median Secchi depths and SAV distribution for 1980, 1983, 1986 and 1989, respectively. In 1980, median mid-channel Secchi depths generally ranged from 0.5-0.7 m; the greatest water clarity was at Maryland Point (Figure V-31). In 1983, growing season median Secchi depths were ≥0.7 m at Rosier Bluff and Marshall Hall in the upper tidal river and at Douglas Point and Maryland Point in the transition zone (Figure V-32). In 1986, the growing season median Secchi depth was 0.5-0.7 m–the lowest values (~0.5 m) were at Indian Head and Quantico where plants were still sparse (Figure V-33). In 1989, Secchi depth at Quantico (0.9 m) was unusually high compared with previous years (Figure V-34). No trend in Secchi depth was found in USGS data for 1979-1983 (Table V-7). MDE data for 1983-1989 (Table V-8) indicate a downward trend of 0.06 m/yr at Hatton Point and 0.05 m/yr at Marshall Hall. This suggests water clarity was unusually good in 1983 in the upper tidal river. Combined data from 1979-1988 show an upward trend of 0.04 m/yr at Quantico (Table V-8). This improvement in water clarity may be responsible for the increase in SAV during 1987-1989 (Figures V-28 and V-30) in this reach of the river.

At Hatton Point, anual median Secchi depth was about 0.6 m during 1980-1983 and then increased to >0.65 m during 1984-1988 (Figure V-35). In 1989, there was a decline in *H. verticillata* and annual median Secchi depth (to 0.5 m) at Hatton Point. At Indian Head, annual median Secchi depth was <0.5 m during 1980-1981, but was >0.6 m during 1983-1989 except for 1986 (Figure V-36). In spite of these relatively large Secchi depths, there was virtually no vegetation at this station until 1987. At Douglas Point, annual median Secchi depth was variable over the period–<0.6 m in 1981, 1985, and 1986, and >0.6 m during the other years (Figure V-37).

During 1983, there was a massive blue-green algal bloom in the lower tidal river at Indian Head, Marshall Hall, and Quantico that eventually reached the vicinity of Rosier Bluff in late August (Metropolitan Washington of Governments 1984). The MDE data do not reflect the presence of this bloom. A series of USGS longitudinal cruises in 1983, however, intended to monitor progress of the bloom, show that median Secchi depths were ≤0.5 m from Marshall Hall to Douglas Point (Figure V-38). USGS data were collected during the algae bloom and do not depict seasonal conditions. Figure V-39 demonstrates the variability of light conditions in the river.

Secchi depths necessary for revegetation and/or expansion of SAV may differ from those necessary to maintain viable populations. Hundreds of Secchi depth measurements in the tidal river and transition zone have been made by USGS since 1979. The yearly means for these Secchi depths are summarized by reach in Table V-6 for 1978-1981, 1983, 1985, and 1986 (the years with a good seasonal distribution

Table V-7. Trend results from USGS data, 1979-1983. Trends are reported if significance level is <0.05 [-indicates downward trend; 0 indicates no trend; * indicates not tested; trend slope values for nutrients and TSS in mg/l/yr; trend slope values for chlorophyll *a* in µg/l/yr; TSS is total suspended solids; DIP is dissolved inorganic phosphorus; TNH4 is total ammonia; DNH4 is dissolved ammonia; N02+N03 is nitrate plus nitrite; CHLA is chlorophyll *a*; NA means not applicable].

Station	Surface (C) or X-Section Average (X)	TSS	Secchi	DIP	TNH4	DNH4	NO2+ NO3	CHLA
GP	C	*	0	*	*	*	*	0
	X	0	*	0	0	0	0	0
RB	C	*	0	0	*	0	0	0
	X	0	*	0	0	0	0.6	0
HP	C	*	0	*	*	*	*	*
	X	0	*	0	0	-0.2	0.3	13
MH	C	*	0	*	*	*	*	*
	X	0	*	0	0	0	0	0
IH	C	*	0	*	*	*	*	0
	X	0	*	0	0	0		
Q	C	0	0	0	0	0	0	0
	X	0	*	0	0	0	0	0
DP	C	0	0	0	0	0	0	0
	X	NA	NA	0	0	0	0	0
MP	C	0	0	0	*	0	0	0
	X	NA	NA	0	*	0	0	0

Table V-8. Trends in MDE water quality data, 1983-1989. Trends are reported if significance level is <0.05 [- indicates down trend; 0 indicates no trend; trend slope for Secchi depth is in m/yr; trend slope for nutrients and TSS is in mg/l/yr; TSS is total suspended solids; DIP is dissolved inorganic phosphorus; TNH4 is total ammonia; N02+N03 is nitrate plus nitrate; CHLA is chlorophyll *a*].

Station	TSS	Secchi	DIP	TNH4	NO2+ NO3	CHLA
HP	0	-0.06	0	0	0	0
MH	0	-0.05	0	0	0	0
IH	-1.3	0	0	0	0	0
Q	-1.5	0	0	0.01	0.09	0
DP	0	0	0	0	0.09	0
MP	0	0	0	0	0	0

Table V-9. Trend results for combined USGS, MDE, and DC data. Time period for all stations is 1979-1988. Trends are reported if significance level is <0.05 [-indicates down trend; 0 indicates no trend; a blank indicates that either USGS, DC, or MDE data are missing; trend slope for Secchi depth in m/yr; trend slope for TSS and nutrients in mg/l/yr; trend slope for chlorophyll *a* in µg/l/yr; TSS is total suspended solids; DIP is dissolved inorganic phosphorus; TNH4 is total ammonia; DNH4 is dissolved ammonia; N02+N03 is nitrate plus nitrate; CHLA is chlorophyll *a*; NA is not applicable].

Station	TSS	Secchi	DIP	TNH4	DNH4	NO2+ NO3	CHLA
GP	0	0	NA	0	0	0.10	0
RB	0	0	NA		0	0.13	0
HP	0	0	NA	0	NA	0.05	0
MH	0	0	NA	0.01	0	0.10	0
IH	-2	0	NA	0	NA	0.07	-3.1(-2.1)
Q	-2	0.04	NA	0	NA	0.07	-1.7
DP	0	0	0	NA	NA	0	0
MP	0	0	0	NA	NA	0	0

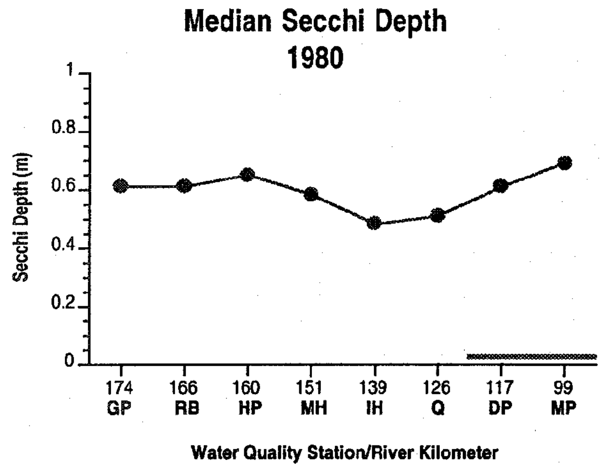

Figure V-31. April–October 1980 median Secchi depth by station in the Potomac River. Shaded area indicates 1980 SAV distribution in the river.

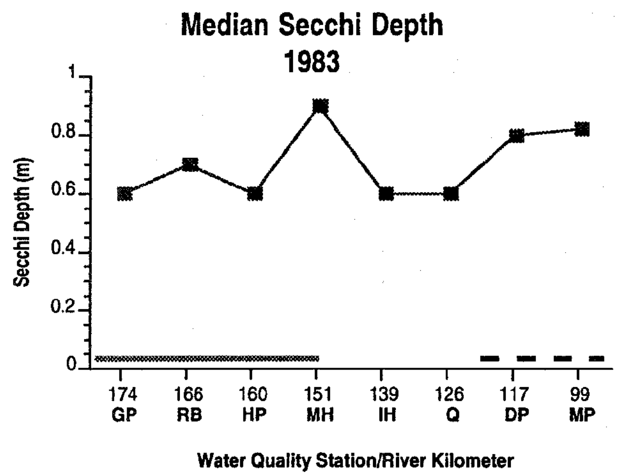

Figure V-32. April–October 1983 median Secchi depth by station in the Potomac River. Shaded area indicates 1983 SAV distribution in the river. Dashed line indicates period with no SAV distribution data.

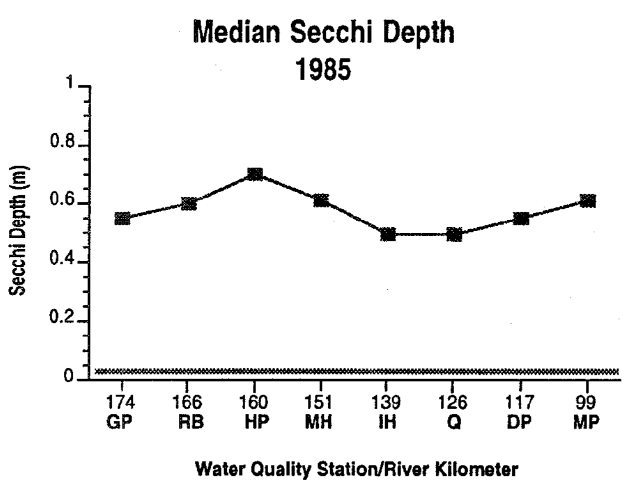

Figure V-33. April–October 1986 median Secchi depth by station in the Potomac River. Shaded area indicates 1986 SAV distribution in the river.

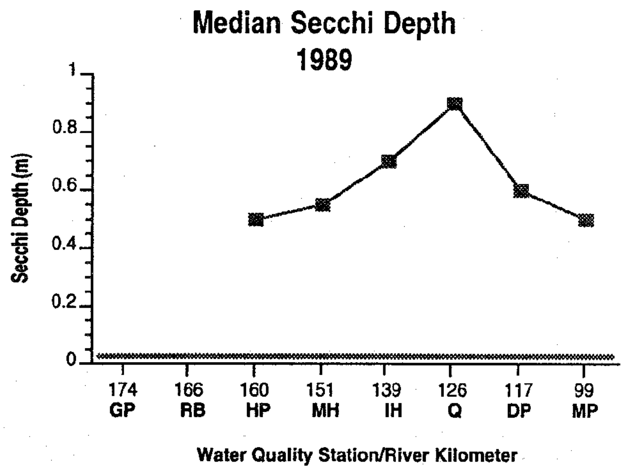

Figure V-34. April–October 1989 median Secchi depth by station in the Potomac River. Shaded area indicates 1989 SAV distribution in the river.

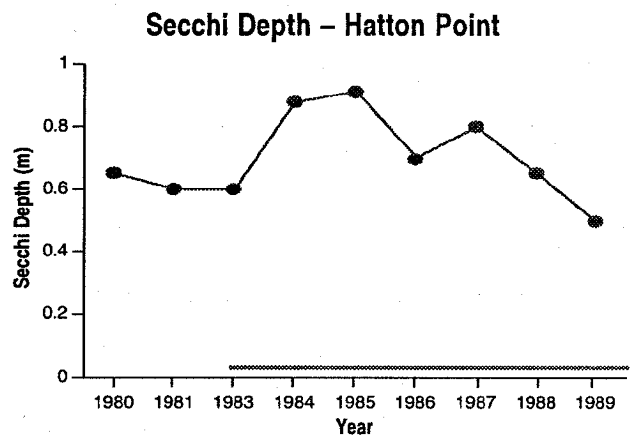

Figure V-35. Median Secchi depth at Hatton Point (upper tidal Potomac River), 1980-1989. Shaded area indicates annual SAV presence at Hatton Point.

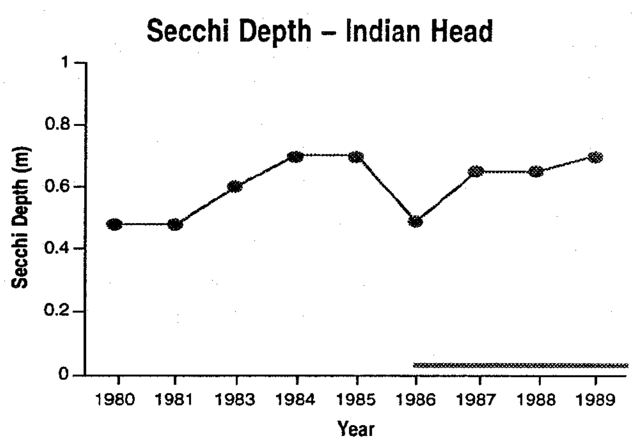

Figure V-36. Median Secchi depth at Indian Head (lower tidal Potomac River), 1980-1989. Shaded area indicates annual SAV presence at Indian Head.

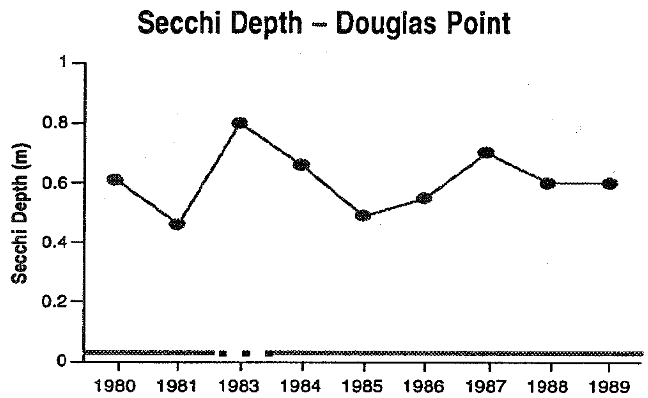

Figure V-37. Median Secchi depth at Douglas Point (transition zone of Potomac Estuary River), 1980-1989. Shaded area indicates annual SAV presence at Douglas Point. Dashed line indicates period with no SAV distribution data at Douglas Point.

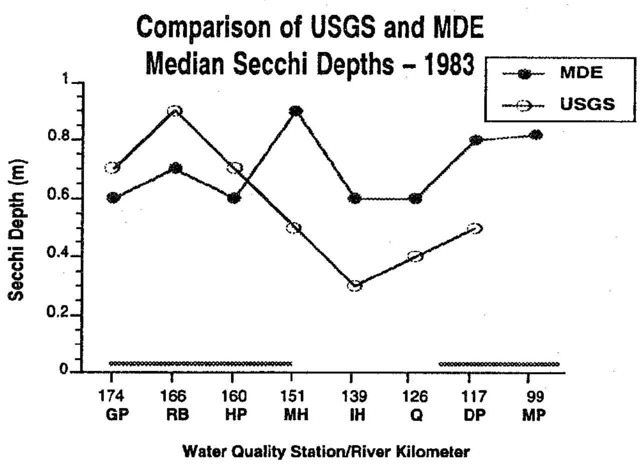

Figure V-38. April–October 1983 median Secchi depths for MDE and USGS stations in the Potomac River. Shaded area indicates 1983 SAV distribution in the river.

of data). These data, and the data presented in Figures V-31 through V-38, suggest that plant survival in the tidal river is unlikely at median or mean (April-October) Secchi depths <0.5 m; whereas growing season median or mean seasonal Secchi depths ≥0.7 m result in revegetation and expansion in coverage. When growing season median or mean Secchi depths lie between 0.5 and 0.7 m, other factors (such as available sunshine, water temperature, or even reproductive success in the previous year) probably play a major role in determining SAV increase or decrease. It appears that Secchi depth limits may be lower in the transition zone; that is, SAV survives at lower mean Secchi depths in the transition zone than in the tidal river, possibly because the tidal range is less.

Light Attenuation Coefficient

Light attenuation was not measured routinely in any of the tidal Potomac River and Estuary data sets. The only measurements directly available were from various special studies conducted by USGS over the past ten years. Based on simultaneous measurements in 1985-1986, Secchi depth can be related to light attenuation in the tidal Potomac River and transition zone using the equation: light attenuation coefficient = 1.38/ Secchi depth (Carter and Rybicki 1990).

Transplant studies in 1980-1981 showed that SAV survived and grew when light attenuation was <2.7 m^{-1}, whereas SAV was not established when light attenuation was ≥2.7 m^{-1} (Carter and Rybicki 1985). During the 1987 growth experiments, light attenuation coefficient values in Pohick Bay (no SAV) ranged from 2.4-8.8 m^{-1} with virtually no SAV survival in unlit cages (Carter and Rybicki, unpublished data). The 1985-1986 light attenuation studies showed that mean monthly light attenuation coefficients were significantly greater in the lower tidal river than in the upper tidal river (Figures V-39 and V-40) (Carter and Rybicki 1990), and SAV was significantly less abundant

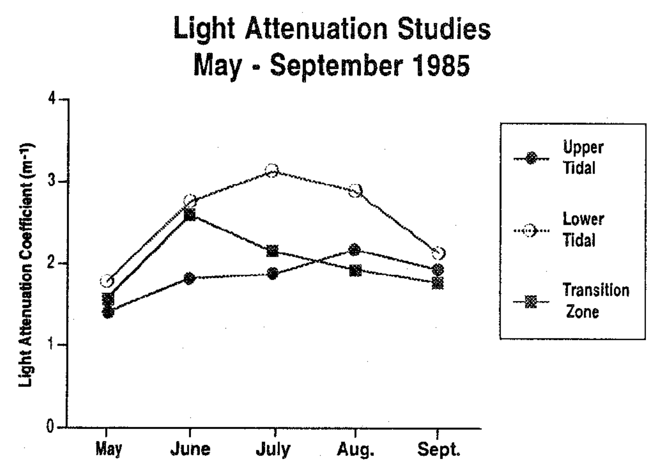

Figure V-39. Monthly mean light attenuation coefficients from studies performed in the upper and lower tidal Potomac River and the transition zone of the Potomac Estuary in 1985 (Carter and Rybicki 1990).

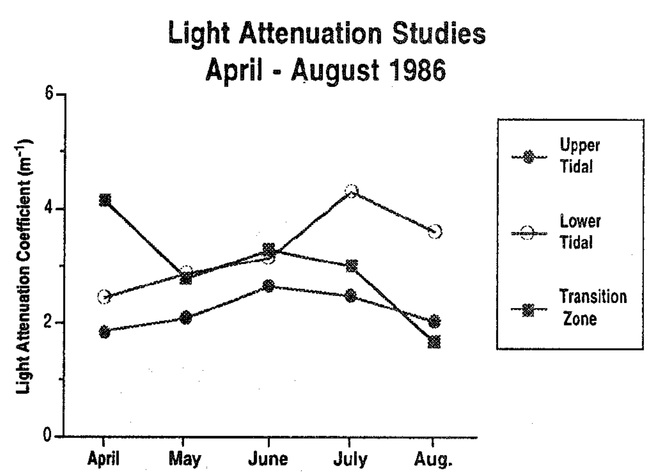

Figure V-40. Monthly mean light attenuation coefficient from studies performed in the upper and lower tidal Potomac River and the transition zone of the Potomac Estuary in 1986 (Carter and Rybicki 1990).

in the lower tidal river than in the upper tidal river. Mean seasonal light attenuation coefficients for the upper tidal river, lower tidal river, and transition zone for 1985 (May-September) were 1.8, 2.4, and 2.0 m^{-1}, respectively; and for 1986 (April-August), they were 2.2, 3.3, and 2.7 m^{-1}, respectively.

On the basis of these studies, mean seasonal light attenuation coefficients $\geq$2.4 m^{-1} can be associated with failure of revegetation in the tidal river, whereas coefficients $\leq$2.2 m^{-1} are associated with the spread of SAV. Established populations, such as those in the transition zone, appear to survive at higher light attenuation coefficients ($\leq$2.7 m^{-1}) than those necessary for revegetation or expansion. Conversion of Secchi depth limits mentioned above show a Secchi depth of 0.5 m to be equivalent to a light attenuation coefficient of 2.8 m^{-1}, and a Secchi depth of 0.7 m to be equivalent to a light attenuation coefficient of 2.0 m^{-1}. At a light attenuation coefficient of 2.8 to 2.0, other factors can play a role in SAV success; whereas, at a light attenuation coefficient of >2.8 m^{-1}, plants are generally not found.

Total Suspended Solids

Growing season median total suspended solids concentrations ranged from 9.5 to 30 mg/l in 1980 (Figure V-41). In the oligohaline transition zone, median total suspended solids concentrations were $\leq$15.5 mg/l. These relatively low concentrations of total suspended solids were present in the only reach of the Potomac River within the study area where SAV was present during the 1980-1982 period. Quantico had the lowest median concentration, but was unvegetated because the median chlorophyll *a* concentration at Quantico was 42 µg/l. In 1983, the year SAV returned to the upper tidal river reach, median total suspended solids concentrations at all vegetated stations were $\leq$15 mg/l (Figure V-42). Median total suspended solids concentrations were $\leq$16 mg/l, except at Quantico and Douglas Point in 1986 (Figure V-43). By this time, SAV had spread into the lower tidal river reach between Marshall Hall and Indian Head as water quality improved in the reach. In 1989, median total suspended solids concentrations (15-18 mg/l) were slightly higher at stations where *H. verticillata* declined (Hatton Point and Marshall Hall) than at stations where SAV increased (Indian Head and Quantico) (Figure V-44).

At Hatton Point, all concentrations were <15 mg/l during and after reestablishment of SAV in 1983, except during 1988, when they increased to 21.9 mg/l resulting in a slight decline in SAV cover (Figure V-45). The serious decline in *H. verticillata* cover at Hatton Point in 1989 is discussed below under the section on climatic variation (Figure V-29). At Indian Head, median total suspended solids concentrations declined to 14.5-16 mg/l during 1984 -1987 (Figure V-46). By 1987, there was sparse SAV cover near Indian Head (Figure V-30). In 1988, SAV increased slightly and then greatly in 1989, when total suspended solids declined to 12 mg/l (Figure V-30 and Figure V-46, respectively). At Douglas Point, median total suspended solids concentrations have fluctuated from 11 to 22 mg/l during 1980-1989 (Figure V-47). SAV cover was relatively sparse until 1989 when total suspended solids concentrations declined to 12 mg/l and SAV increased.

During the 1979-1988 period, there were statistically significant downward trends in total suspended solids concentrations in the lower tidal river reach at Indian Head and Quantico (Table V-9). The downward trend of 2 mg/l per year corresponds directly with the reestablishment of SAV in this reach of the river (Figures V-28 and V-30).

Growing season median total suspended solids concentrations of $\leq$15-16 mg/l are generally associated with expansion of SAV in the tidal river and the oligohaline transition zone. When concentrations are between 16 and 20 mg/l, SAV cover in established populations may increase, decrease or remain the same, depending on local conditions. For example, SAV cover remained nearly constant at Marshall Hall and Indian Head in 1988 when total suspended solids increased to 17.5 and 19 mg/l, respectively. In 1989, SAV increased at Maryland Point when the concentration was 19 mg/l (Figures V-28 and V-30). Total suspended solid concentrations >20 mg/l are associated with a lack of or a decline in SAV.

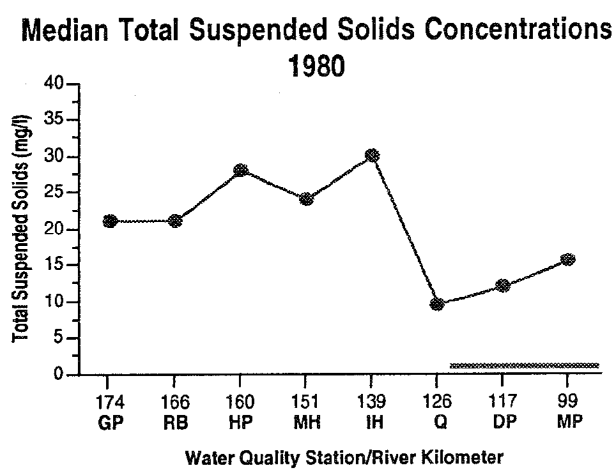

Figure V-41. April–October 1980 median total suspended solids concentrations by station in the Potomac River. Shaded bar indicates 1980 SAV distribution in the river.

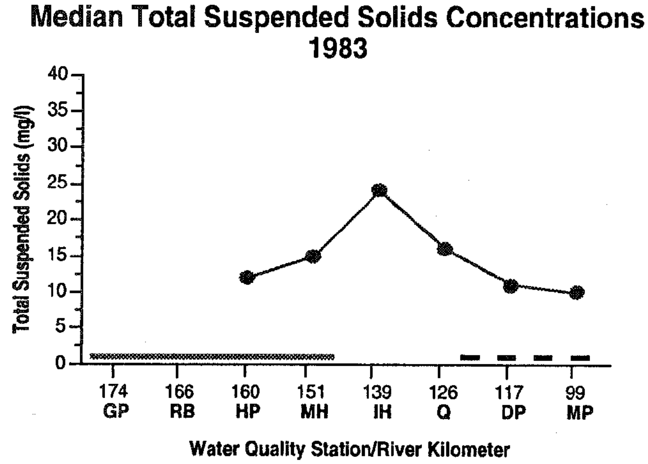

Figure V-42. April–October 1983 median total suspended solids concentrations by station in the Potomac River. Shaded bar indicates 1983 SAV distribution in the river. Dashed line indicates period with no SAV distribution data.

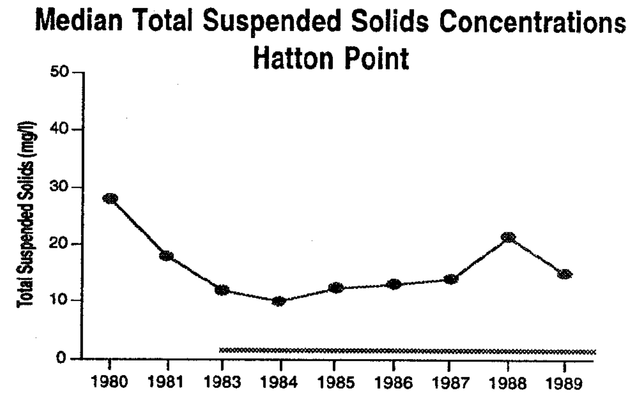

Figure V-45. Median total suspended solids concentrations at Hatton Point in the upper tidal Potomac River, 1980-1989. Shaded area indicates annual SAV presence at Hatton Point.

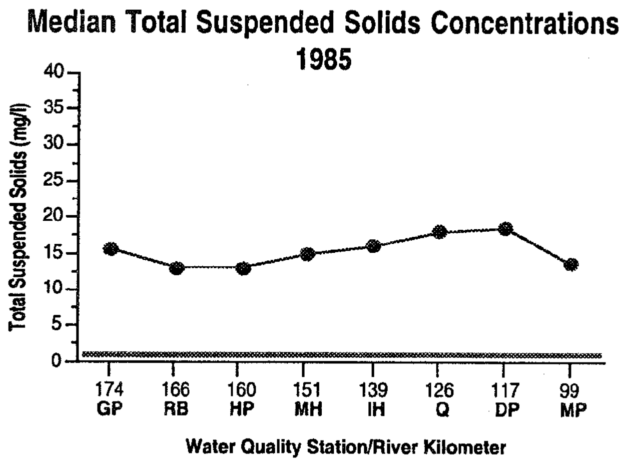

Figure V-43. April–October 1986 median total suspended solids concentrations by station in the Potomac River. Shaded bar indicates 1986 SAV distribution in the river.

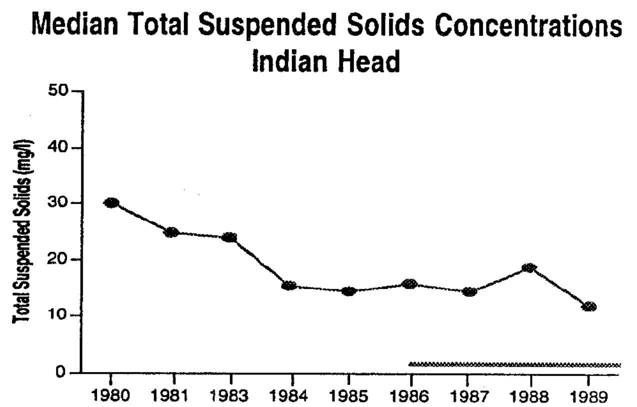

Figure V-46. Median total suspended solids concentrations at Indian Head in the lower tidal Potomac River, 1980-1989. Shaded area indicates annual SAV presence at Indian Head.

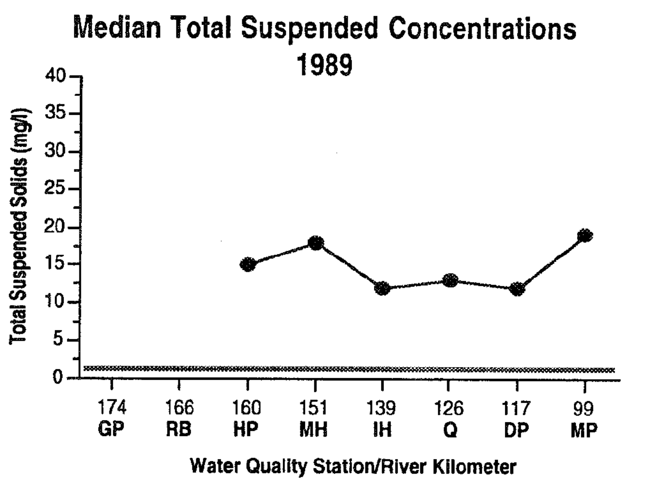

Figure V-44. April–October 1989 median total suspended solids concentrations by station in the Potomac River. Shaded bar indicates 1989 SAV distribution in the river.

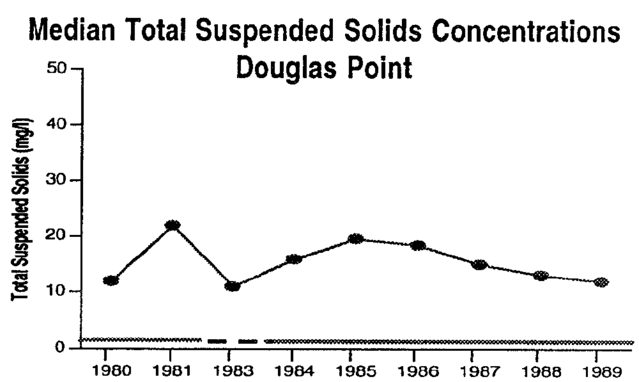

Figure V-47. Median total suspended solids concentrations at Douglas Point in the oligohaline transition zone of the Potomac Estuary 1980-1989. Shaded area indicates annual SAV presence at Douglas Point. Dashed line indicates period with no SAV distribution data at Douglas Point.

Chlorophyll a

Figures V-48 through V-51 show growing season median chlorophyll *a* concentrations and SAV distribution for 1980, 1983, 1986, and 1989. In 1980, median chlorophyll *a* concentrations ranged from 15-27 µg/l in the upper tidal river. Downriver, concentrations peaked at 42 µg/l at Quantico and decreased to 20 µg/l at Maryland Point where SAV was present (Figure V-48). In 1983, median chlorophyll *a* concentrations peaked at 16.7 µg/l at Indian Head because of the *Microcystis* phytoplankton bloom during the summer (Figure V-49). In 1986 and 1989, median chlorophyll *a* concentrations at all stations were <15 µg/l (Figures V-50 and V-51, respectively). A statistically significant downward trend in chlorophyll *a* concentration (1.7-3.1 µg/l per year) was observed at Indian Head and Quantico from 1979 to 1988 (Table V-9).

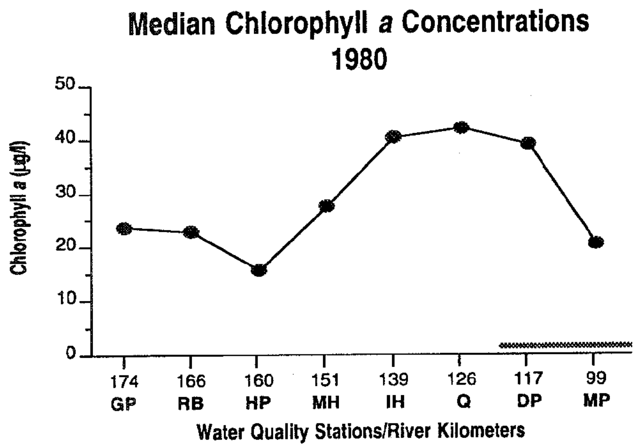

Figure V-48. April-October 1980 median chlorophyll *a* concentrations by station in the Potomac River. Shaded bar indicates 1980 distribution of SAV in the river.

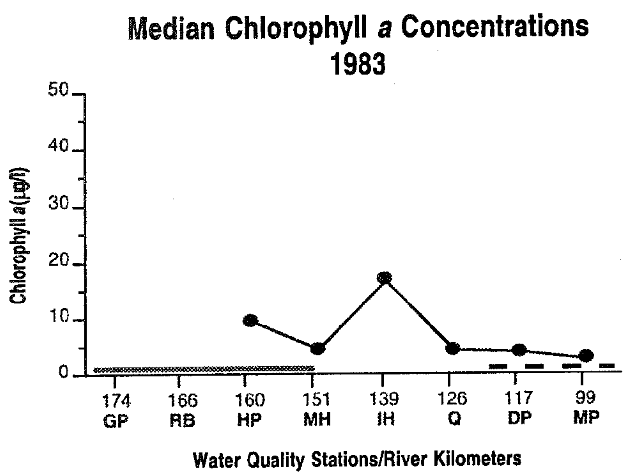

Figure V-49. April–October 1983 median chlorophyll *a* concentrations by station in the Potomac River. Shaded bar indicates 1983 distribution of SAV in the river. Dashed line indicates period with no SAV distribution data.

Figures V-52 through V-54 show yearly median chlorophyll *a* concentrations at Hatton Point, Indian Head, and Douglas Point. At Hatton Point, the median chlorophyll *a* concentration was <10 µg/l in all years except 1980 and 1981–years when there was no SAV (Figure V-52). At Indian Head, chlorophyll *a* concentrations were >15 µg/l during 1980-1985 and declined to <15 µg/l during 1986-1989 (Figure V-53). Between 1986 and 1989, SAV increased at Indian Head. The greatest increase in cover at Indian Head occurred during 1989, a year when median chlorophyll *a* concentrations declined to 8.6 µg/l and median total suspended solids concentrations were 12 mg/l (Figures V-30, V-46, and V-53, respectively). At Douglas Point, median chlorophyll *a* concentrations were <10 µg/l in all years except 1980-1981 and 1984 (Figure V-54). In 1984, the median concentration was 14.8 µg/l. During 1980-1988, SAV cover was sparse or absent, increasing to a maximum in 1989 (Figure V-30).

During the light attenuation study in 1985-1986 (Carter and Rybicki 1990), USGS collected nearshore chlorophyll *a* data (water depth ≤3 m). Chlorophyll *a* concentrations were higher in the lower tidal river than in the upper tidal river or transition zone in both years. Mean monthly chlorophyll *a* concentrations in the tidal river generally increased from April or May, peaked in July or August, and then decreased. Concentrations were low, <15 µg/l, and relatively constant in the transition zone. In June 1985, a phytoplankton bloom began in the lower tidal river and spread into the upper tidal river in early July. This bloom persisted into September at Gunston Cove (GC) and Elodea Cove (EC), reaching peak concentrations of 110 and 89 µg/l, respectively. MDE and USGS May-September medians for 1985 are compared in Figure V-55. April and October chlorophyll *a* concentrations tend to be lower than mid-summer concentrations. By removing the data from these two months, median values for most stations increased, demonstrating the presence of the phytoplankton bloom. The differences between MDE and USGS data arise partially because of differences between nearshore and mid-channel data and partially because of the extreme variability of phytoplankton distribution during large blooms.

High chlorophyll *a* concentrations (in excess of 30 µg/l), as observed during phytoplankton blooms over short periods of time, do not seem detrimental to well-established SAV populations. However, high chlorophyll *a* values can prevent revegetation if they occur during a critical time of reestablishment. Growing season median chlorophyll *a* concentrations of <15 µg/l are generally associated with SAV expansion, whereas growing season median chlorophyll *a* concentrations >15 µg/l are usually associated with SAV decline or absence.

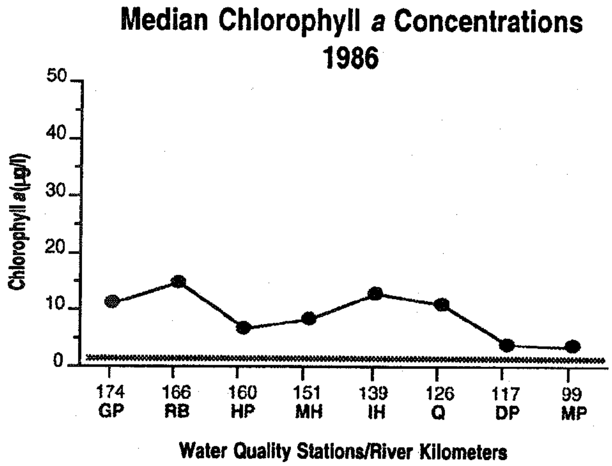

Figure V-50. April–October 1986 median chlorophyll *a* concentrations by station in the Potomac River. Shaded bar indicates 1986 distribution of SAV in the river.

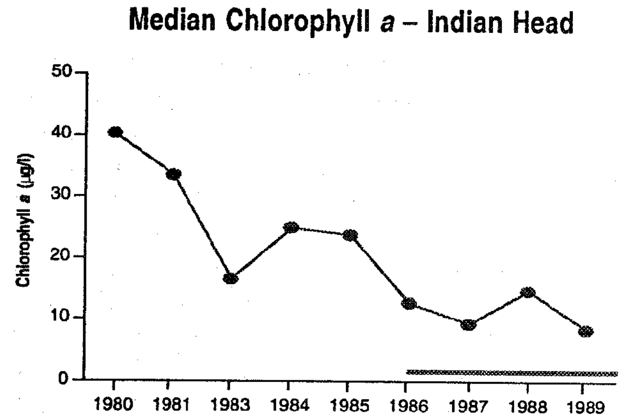

Figure V-53. Median chlorophyll *a* concentrations at Indian Head in the lower tidal Potomac River, 1980-1989. Shaded area indicates annual SAV presence at Indian Head.

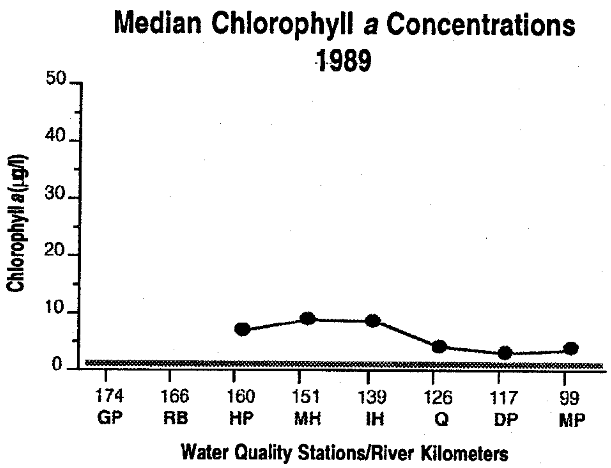

Figure V-51. April–October 1989 median chlorophyll *a* concentrations by station in the Potomac River. Shaded bar indicates 1989 distribution of SAV in the river.

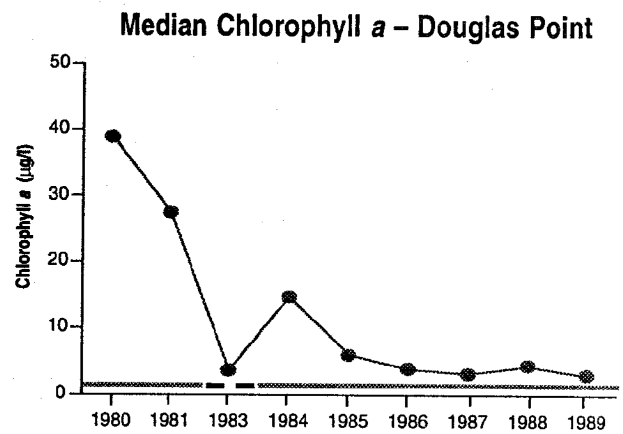

Figure V-54. Median chlorophyll *a* concentrations at Douglas Point in the oligohaline transition zone, 1980-1989. Shaded area indicates annual SAV presence at Douglas Point. Dashed line indicates period with no SAV distribution data.

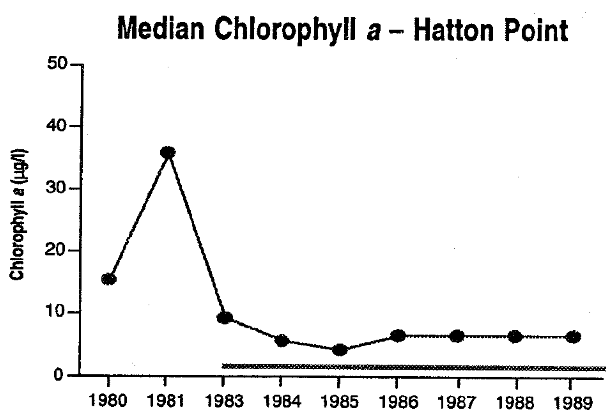

Figure V-52. Median chlorophyll *a* concentrations at Hatton Point in the upper tidal Potomac River, 1980-1989. Shaded area indicates annual SAV presence at Hatton Point.

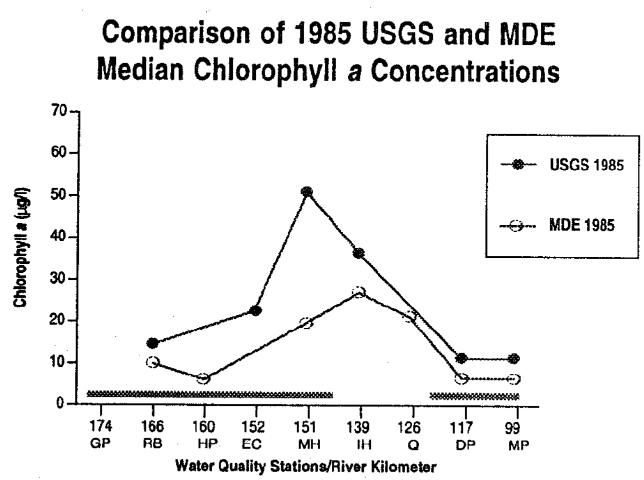

Figure V-55. May-September 1985 median chlorophyll *a* concentrations at USGS and MDE stations in the Potomac River.

Relation Between Total Suspended Solids and Chlorophyll a

Although habitat requirements for total suspended solids and chlorophyll *a* have been developed based on the relationship between each parameter and SAV success, it should be remembered that these two parameters are not independent. At high chlorophyll *a* concentrations, phytoplankton contributes to total suspended solids concentrations. In addition, both parameters must be below the habitat requirement. If one parameter is below when the other is above the habitat requirement, SAV may be absent or decline. In 1985, there was little SAV at Quantico and almost none at Indian Head (Figure V-30). Figure V-56 shows that total suspended solids and chlorophyll *a* concentrations at Quantico were close to the suggested habitat requirements, while the median chlorophyll *a* concentration at Indian Head exceeded the chlorophyll *a* habitat requirement.

Dissolved Inorganic Nitrogen

Median dissolved inorganic nitrogen was calculated by adding median nitrate plus nitrite to median dissolved ammonia (DC data) or median total ammonia (USGS and MDE data). Figures V-57 through V-60 show growing season median dissolved inorganic nitrogen concentrations for 1980, 1983, 1986, and 1989. Concentrations in all years decrease downriver. The highest concentrations (about 2 mg/l) were in the upper tidal river. The lowest concentrations (0.5 mg/l) were from Indian Head to Maryland Point in 1980, increasing to >1.5 mg/l in this reach by 1989. No trends were calculated for dissolved inorganic nitrogen.

Median dissolved inorganic nitrogen concentrations at Hatton Point were about 1.5 mg/l in 1980-1981 and increased to about 2 mg/l in subsequent years (Figure V-61). Median concentrations at both Indian Head and Douglas

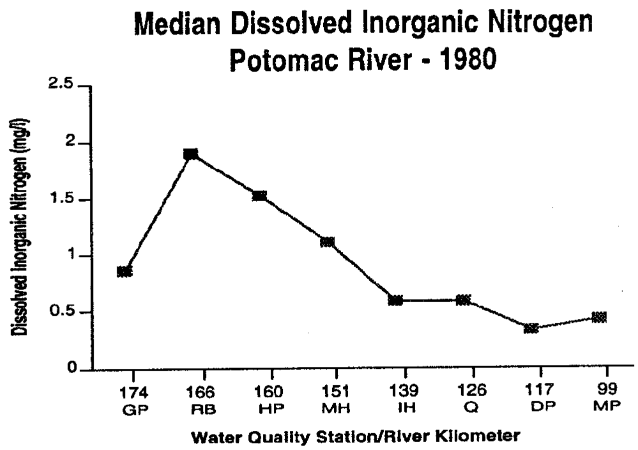

Figure V-57. April–October 1980 median dissolved inorganic nitrogen concentrations by station in the Potomac River.

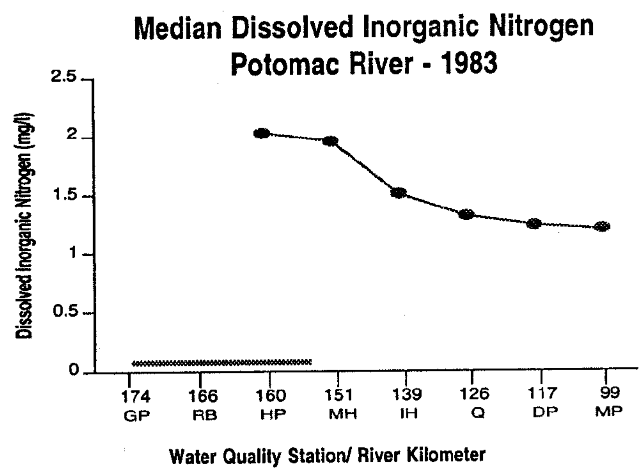

Figure V-58. April–October 1983 median dissolved inorganic nitrogen concentrations by station in the Potomac River. Shaded area indicates 1983 SAV distribution in the river.

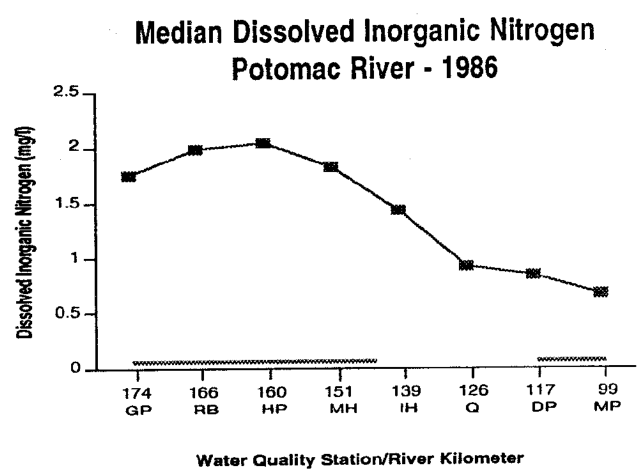

Figure V-59. April–October 1986 median dissolved inorganic nitrogen concentrations by station in the Potomac River. Shaded area indicates 1986 SAV distribution in the river.

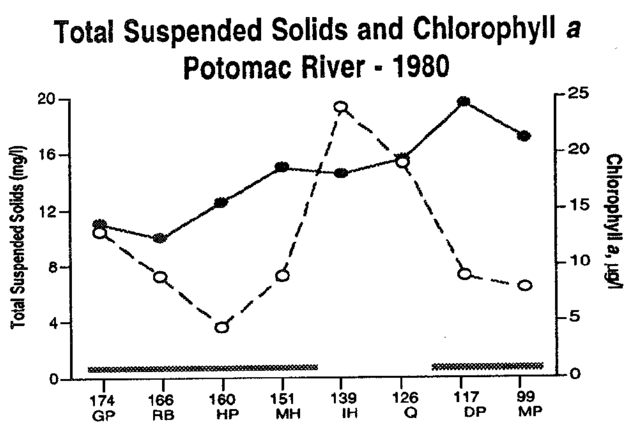

Figure V-56. Median total suspended solids (●) and chlorophyll *a* (○) concentrations in the Potomac River, 1985. Shaded area indicates the 1985 SAV distribution in the river.

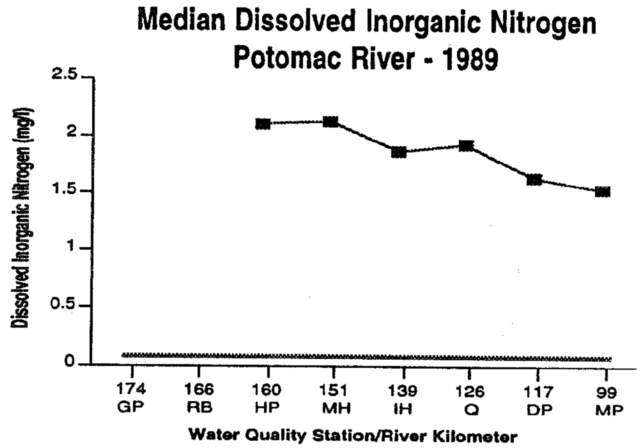

Figure V-60. April-October 1989 median dissolved inorganic nitrogen concentrations by station in the Potomac River. Shaded area indicates 1989 SAV distribution in the river.

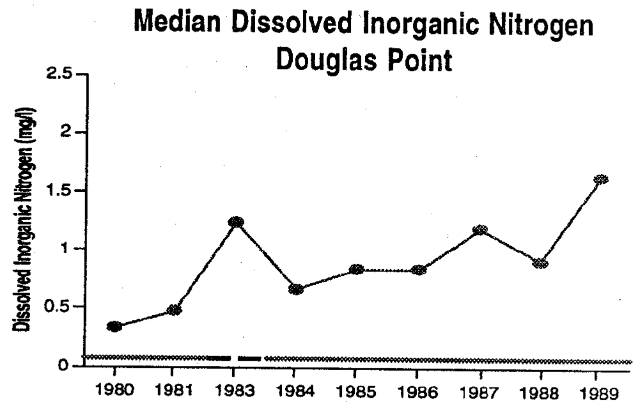

Figure V-63. Median dissolved inorganic nitrogen concentrations at Douglas Point in the oligohaline transition zone of the Potomac Estuary, 1980-1989. Shaded area indicates annual SAV presence at Douglas Point. Dashed line indicates period with no SAV distribution data at Douglas Point.

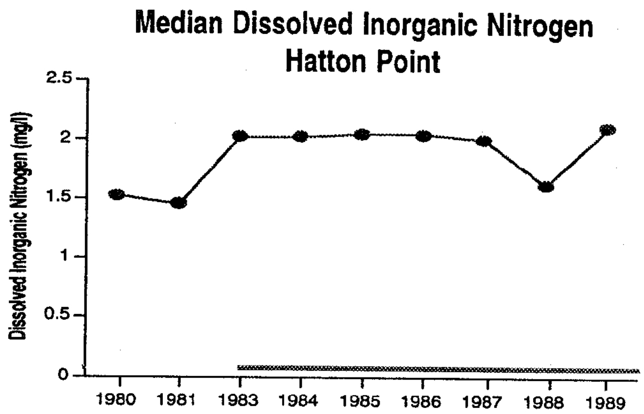

Figure V-61. Median dissolved inorganic nitrogen concentrations at Hatton Point in the upper Potomac River 1980-1989. Shaded area indicates annual SAV presence at Hatton Point.

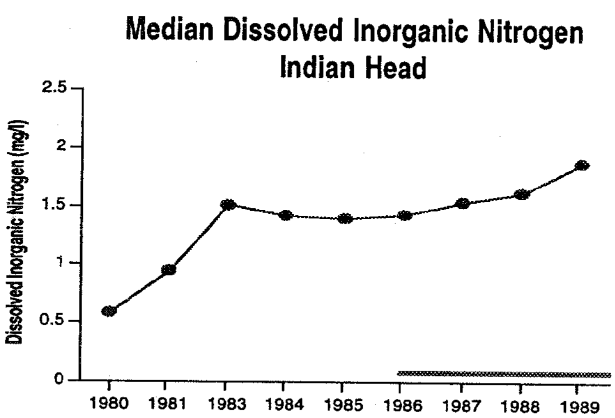

Figure V-62. Median dissolved inorganic nitrogen concentrations at Indian Head in the lower tidal Potomac River 1980-1989. Shaded area indicates annual SAV presence at Indian Head.

Point rose steadily from about 0.5 mg/l in 1980 to >1.5 mg/l by 1989 (Figures V-62 and V-63, respectively). There does not appear to be a causal relationship between median dissolved inorganic nitrogen and SAV success or failure in the tidal Potomac River and Estuary. Nitrogen concentrations are not limiting for phytoplankton, so a year with unusually low discharge and high water temperature could cause a bloom and affect SAV.

Because of their influence on algal growth, ammonia concentrations may influence SAV survival more than dissolved inorganic nitrogen (Shultz 1989). Algae use ammonia preferentially and may not switch to nitrate metabolism until ammonia concentrations are <0.014 mg/l (Shultz 1989). The reduction in ammonia loadings from the Blue Plains Sewage Treatment Plant after 1980 may have caused the decline in median chlorophyll *a* concentration in the upper tidal river.

Figure V-64 shows growing season median ammonia concentrations for 1980, 1983, 1986, and 1989. Total ammonia was ≤0.2 mg/l at Indian Head, Quantico, Douglas Point, and Maryland Point in all years, and ≤0.4 mg/l from Geisboro Point to Marshall Hall for all years except 1980 when it was >0.6 mg/l. USGS data (1979-1983) (Table V-7) show a downward trend in dissolved ammonia of 0.2 mg/l per year at Hatton Point but no trend in total ammonia. MDE data from 1983-1989 (Table V-8) indicate an upward trend of 0.01 mg/l per year in total ammonia at Quantico. Combined USGS-MDE-DC data for 1979-1988 (Table V-9) show no trends in dissolved ammonia and an upward trend in total ammonia of 0.01 mg/l at Marshall Hall. Growing season median concentrations of ammonia >0.6 mg/l could affect SAV survival.

Concentrations of nitrate plus nitrite were low (≤1 mg/l) in 1980, especially in the oligohaline transition zone (Figure V-65). Since the Blue Plains Wastewater Treatment Plant nitrification facility came on-line in 1981, dissolved and total nitrate plus nitrite concentrations have increased downstream as far as Maryland Point. In 1989, they varied from a high of about 2 mg/l at Hatton Point to a low of about 1.7 mg/l at Maryland Point. In 1989, discharge remained high throughout August and may partially account for the high concentrations of nitrate plus nitrite at Quantico and farther down river. USGS data (1979-1983) (Table V-7) show an upward trend in nitrate plus nitrite of 0.6 mg/l per year at Rosier Bluff and 0.3 mg/l per year at Hatton Point. MDE data (1983-1989) (Table V-8) indicate an upward trend of 0.09 mg/l at Quantico and Douglas Point. Combined USGS-MDE-DC data (1979-1988) (Table V-9) indicate an upward trend of 0.05 to 0.13 mg/l per year at all stations except Maryland Point. Present nitrate plus nitrite concentrations in the tidal river and transition zone (1.7-2 mg/l) are compatible with SAV propagation and survival.

Dissolved Inorganic Phosphorus

Dissolved inorganic phosphorus concentrations were very high in the tidal Potomac River during the 1960s when there was no SAV. In August 1969, dissolved inorganic phosphorus ranged from 0.15 to 0.36 mg/l between the Blue Plains Wastewater Treatment Plant and Indian Head (Jaworski 1969; Jaworski *et al.* 1971). By 1977, dissolved inorganic phosphorus concentrations had decreased to between 0.035 and 0.105 mg/l in that reach. Figures V-66 through V-69 show growing season median dissolved inorganic phosphorus concentrations in 1980, 1983, 1986, and 1989. Dissolved inorganic phosphorus was measured differently by different agencies: USGS 1980-1981 data

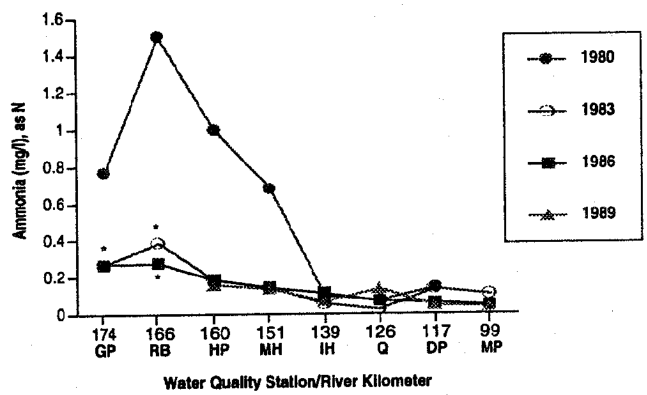

Figure V-64. April–October median ammonia concentrations by station in the Potomac River for 1980, 1983, 1986, and 1989 (* = dissolved ammonia, as N (mg/l)).

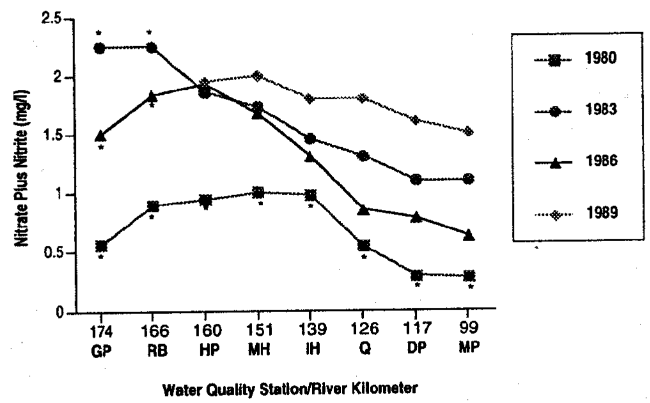

Figure V-65. April–October median nitrate plus nitrite concentrations by station in the Potomac River for 1980, 1983, 1986, and 1989 (* = dissolved nitrate plus nitrite; remainder of the datapoints are total nitrate plus nitrite).

Table V-10. SAV habitat requirements for tidal fresh and oligohaline habitats in the upper Potomac River applied as growing season medians (April-October).

	TIDAL FRESH	OLIGOHALINE
Light Attenuation Coefficient	≤2.2 m^{-1}	≤2.7m^{-1}
Total Suspendid Solids	<15 - 16 mg/l	<15 - 16 mg/l
Chlorophyll *a*	<15 µg/l	<15 µg/l
Dissolved Inorganic Nitrogen	–	-
Dissolved Inorganic Phosphorus	≤0.04 mg/l	<0.07 mg/l

are total soluble phosphorus; DC and MDE data are dissolved inorganic phosphorus. By 1980, continued improvement in sewage treatment had reduced median dissolved inorganic phosphorus concentrations to about 0.04 mg/l (Figure V-66). Generally, dissolved inorganic phosphorus concentrations have remained at ≤0.04 mg/l in the tidal river and between 0.04 and 0.07 mg/l in the transition zone (Figures V-66 through V-69). Figures V-70 through V-72 show median dissolved inorganic phosphorus by year at Hatton Point, Indian Head, and Douglas Point, respectively. Dissolved inorganic phosphorus concentrations at Hatton Point and Indian Head were <0.04 mg/l in all years. Dissolved inorganic phosphorus concentrations at Douglas Point varied between 0.04 and 0.07 mg/l during 1980-1989. USGS, MDE, and DC data show no trends in dissolved inorganic phosphorus for the study period (Tables V-7 through V-9).

Present concentrations of dissolved inorganic phosphorus in the tidal river and transition zone are not adversely affecting SAV. Dissolved inorganic phosphorus concentrations in the transition zone have remained slightly higher than those in the tidal river throughout the 1980-1989 time period. Chlorophyll *a* concentrations in the transition zone, however, are generally <20 µg/l even though dissolved inorganic phosphorus is not limiting. Increasing salinity during the growing season may be a factor in preventing algal blooms such as those found upriver from Quantico. However, because the primary impact of dissolved inorganic phosphorus on SAV appears to be through its effect on algal growth, many other factors, including discharge, water temperature, and sunshine (Bennett *et al.* 1986) must be considered when examining SAV success and failure.

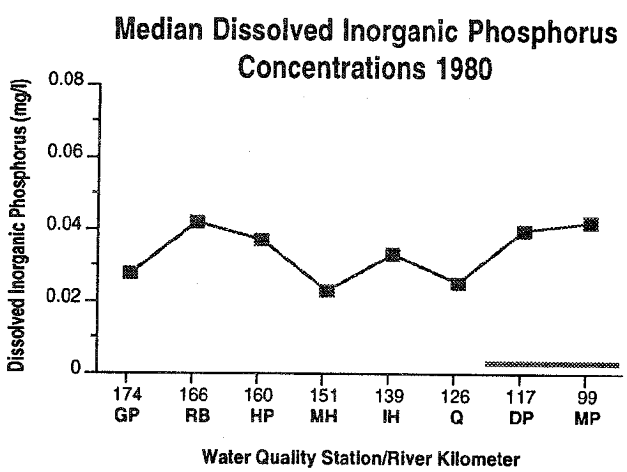

Figure V-66. April–October 1980 median dissolved inorganic phosphorus concentrations by station in the Potomac River. Shaded bar indicates 1980 distribution of SAV in the river.

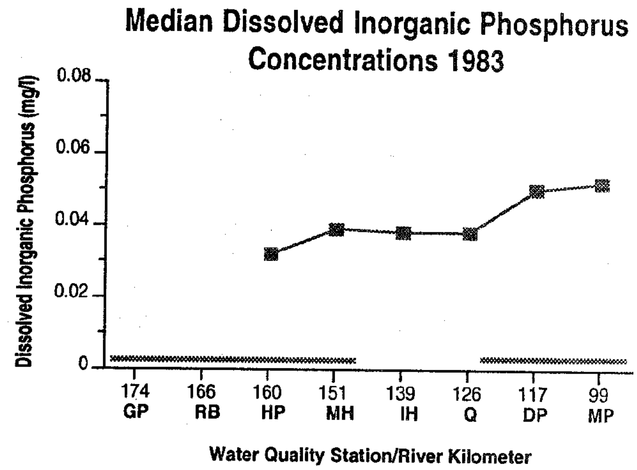

Figure V-67. April-October 1983 median dissolved inorganic phosphorus station in the Potomac River. Shaded bar indicates 1983 distribution of SAV in the river.

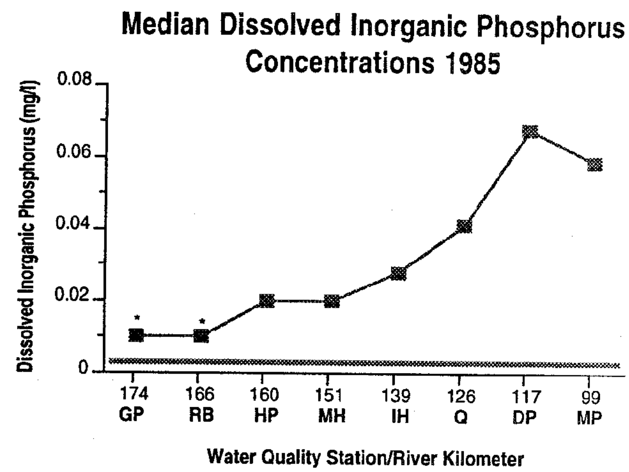

Figure V-68. April–October 1986 mean dissolved inorganic phosphorus concentrations by station in the Potomac River (* is below detection limit). Shaded bar indicates 1986 distribution of SAV in the river.

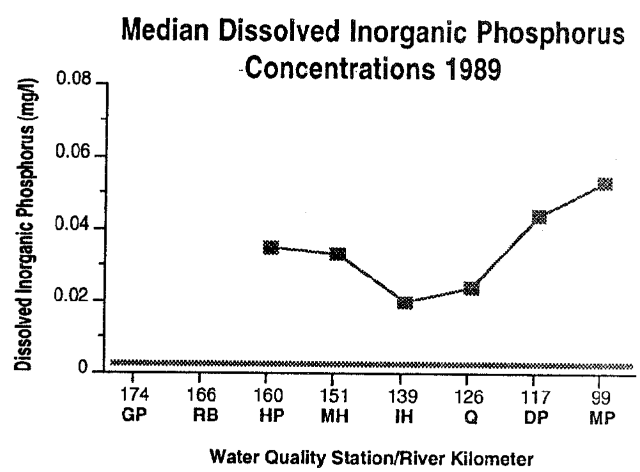

Figure V-69. April–October 1989 median dissolved inorganic phosphorus concentrations by station in the Potomac River. Shaded bar indicates 1989 distribution of SAV in the river.

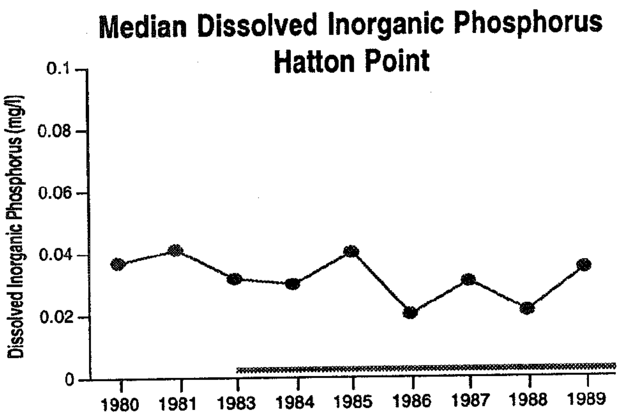

Figure V-70. Median dissolved inorganic phosphorus concentrations at Hatton Point in the upper tidal Potomac River, 1980-1989. Shaded area indicates SAV distribution.

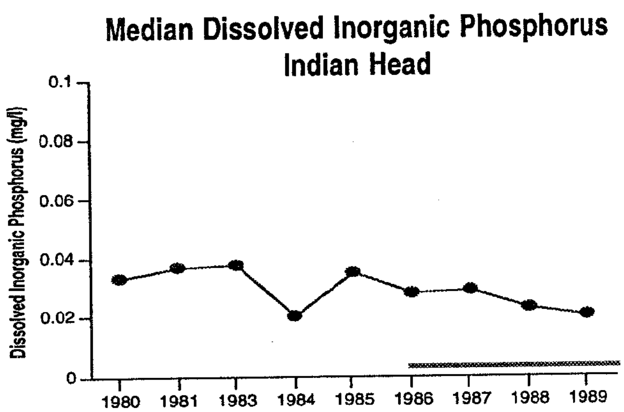

Figure V-71. Median dissolved inorganic phosphorus concentrations at Indian Head in the lower tidal Potomac River, 1980-1989. Shaded area indicates SAV distribution.

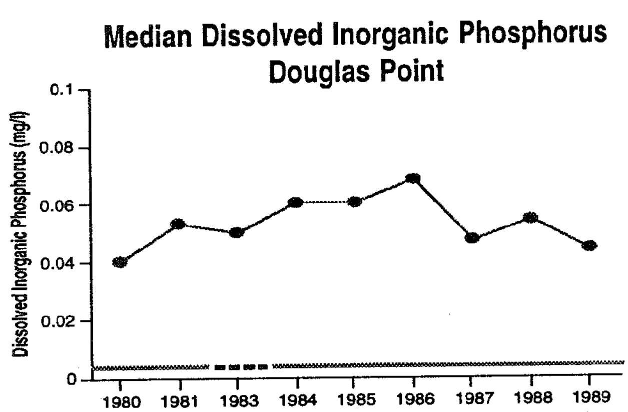

Figure V-72. Median dissolved inorganic phosphorus concentrations at Douglas Point, 1980-1989. Shaded area indicates SAV distribution. Dashed lines indicates period with no SAV distribution data.

Local Climate Variation and Seasonal Considerations

In 1989, the weather was unusually cold, wet, and cloudy. The water clarity was poor in the upper tidal river, resulting in a loss of *H. verticillata* that decreased the SAV population by 70%. Freshwater discharge was high in April and May and remained high through August. Water temperatures were <15 °C until the end of May except for a brief rise to 18 °C in early April. These below average temperatures probably delayed *H. verticillata* tuber germination until early June, or if the tubers sprouted in May, the low temperatures severely retarded plant growth. Secchi depths immediately following germination were low in the upper tidal river (≤0.5 m) and fairly high in the lower tidal river around Indian Head and Quantico (≥0.9 m)–a reversal of the situation found during 1985-1986. Also, during the summer, percent available sunshine was only 46%, significantly below the twenty-year mean. In 1989, *H. verticillata* was limited to shallow water (water less than 1 m in depth) in the upper tidal river. Apparently, adaptation to a tropical climate made it impossible for this plant to cope with a late growth start that was compounded by rapidly rising water temperatures and extremely limited light in June through August. Local climatic variation may be an important consideration in parts of Chesapeake Bay, especially if exotic species comprise a significant proportion of the SAV population.

Seasonal variation in Secchi depth, total suspended solids, and chlorophyll *a* concentrations may be important considerations for SAV growth and survival. Low spring Secchi depths, caused by high total suspended solids, may prevent the regrowth of species such as *V. americana* and *H. verticillata,* which either do not form a surface canopy or form a surface canopy only during the summer. Species such as *M. spicatum*, which form a surface canopy in early spring, may not be adversely affected by low spring Secchi depths if the water clarity improves later in the growing season. Dense beds make their own environment (i.e., they cause sediment deposition and improve water clarity within the bed) (Carter *et al.* 1988). Thus, high total suspended solids and chlorophyll *a* concentrations in the summer and fall do not affect well-established populations but could easily prevent revegetation of downstream reaches by plant fragments.

Summary and Conclusions

SAV distribution has been analyzed with reference to Secchi depth, light attenuation coefficient, and concentrations of total suspended solids, chlorophyll *a*, dissolved inorganic nitrogen (total ammonia, nitrate plus nitrite), and dissolved inorganic phosphorus to determine requirements for maintenance of viable SAV populations and revegetation and expansion of SAV in the tidal Potomac River and Estuary (Table V-10). These analyses showed that:

1) Revegetation and expansion of SAV in the tidal river occurs when growing season median Secchi depths are ≥0.7 m. Revegetation does not occur when growing season median Secchi depths are ≤0.5 m. Between these limits, survival may depend on amount of available sunshine, epiphyte loading, etc. Once plants are established in the tidal river, Secchi depths ≤0.7 m cause plants to be restricted to shallower depths depending on species tolerances. In the transition zone, established SAV populations can survive from year to year at growing season median Secchi depths as low as 0.5 m.

2) Revegetation and expansion of SAV in the tidal river occurs when the growing season median light attenuation coefficient is ≤2.2 m^{-1}. When growing season median seasonal light attenuation coefficients are ≥2.4 m^{-1}, revegetation does not occur. Established populations in the transition zone can survive when growing season median light attenuation coefficients are as high as 2.7 m^{-1}.

3) Revegetation and expansion of SAV in the tidal river and maintenance of SAV populations in the tidal river and transition zone occur when growing season medians for total suspended solids concentrations are ≤15-16 mg/l.

4) Revegetation and expansion of SAV in the tidal river and transition zone occur when growing season median chlorophyll *a* concentrations are ≤15 μg/l. Over the growing and reproductive period, high chlorophyll *a* concentrations can prevent revegetation if they occur at critical times during reestablishment. High chlorophyll *a* concentrations (>30 μg/l), as seen in phytoplankton blooms over short periods of time, do not seem to be detrimental to well-established SAV populations. Transition zone SAV populations are seldom exposed to growing season median chlorophyll *a* concentrations ≥20 μg/l.

5) Dissolved inorganic nitrogen concentrations cannot be conclusively associated with SAV success or failure in the tidal river or transition zone. Concentrations ≥1.5 mg/l are common in both reaches. Growing season median concentrations of ammonia >0.6 mg/l were recorded in the upper tidal river in 1980 when SAV was not present. Such high concentrations of ammonia could affect SAV survival by increasing the likelihood of algae blooms. Revegetation occurred in the upper tidal river when growing season median ammonia concentrations decreased to ≤0.4 mg/l; however, growing season median ammonia concentrations in the lower tidal river were ≤0.4 mg/l in 1980 and revegetation did not occur. Established beds of SAV in the transition zone survived under growing season median ammonia concentrations of 0.4-0.7 mg/l. Revegetation and increased SAV abundance occurred throughout the tidal river despite continually increasing concentrations of nitrate plus nitrite. Growing season median nitrate plus nitrite concentrations, which ranged from 1.7-2 mg/l in 1989, are compatible with SAV propagation and survival.

6) Dissolved inorganic phosphorus concentrations have decreased significantly in the tidal river since the 1960s. Present growing season median concentrations, which are ≤0.04 mg/l in the tidal river and range from 0.04-0.07 mg/l in the transition zone, support revegetation and expansion of SAV.

7) Local climatic conditions including water temperature, amount of available sunshine, discharge, and wind speed and direction are very important in determining the distribution and abundance of SAV, especially in the tidal river. A marked decline in *H. verticillata* coverage in the upper tidal river in 1989 was the result of low spring water temperatures, high discharge and turbidity, and low available sunshine in conjunction with poor water clarity.

Choptank River

During the mid-1980s, a series of studies was undertaken to enhance the understanding of SAV response to water quality in the Choptank River. In these studies, scientists transplanted SAV to areas where it historically grew and monitored the water quality at each transplant site throughout the growing season. Key variables–light attenuation, total suspended solids, chlorophyll *a* , nitrogen, and phosphorus–were identified in both mesocosm experiments and system models as important factors affecting SAV survival in the mid-Chesapeake Bay. The Choptank River has a pronounced water quality gradient as well as a detailed record of historical SAV beds which makes it an ideal study system for associating SAV survival with key environmental parameters. In addition, SAV rapidly recolonized the lower Choptank River during an extended drought from 1986 to 1988. In the studies, approximately 20 water quality parameters were measured and five were found to

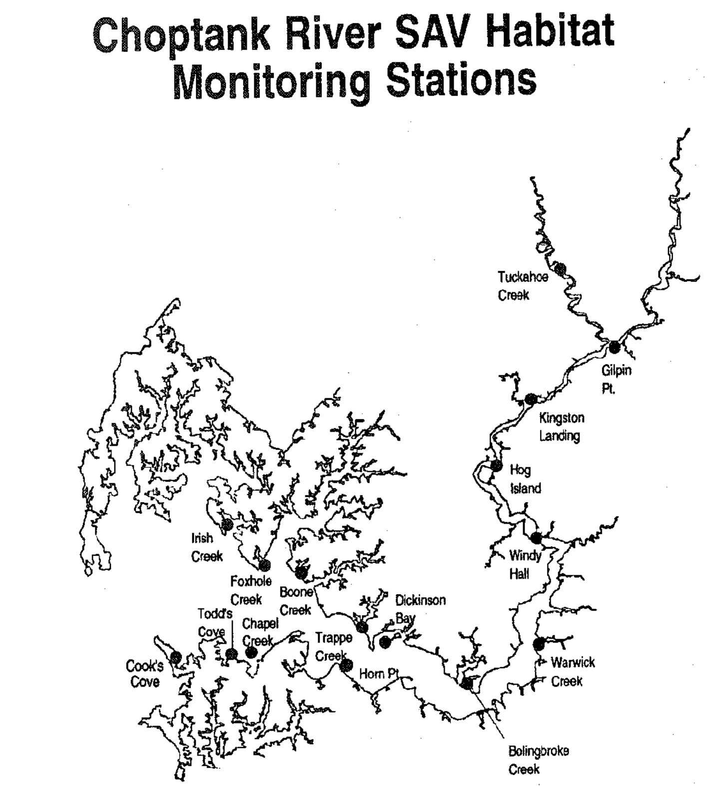

Figure V-73. Choptank River SAV habitat quality monitoring stations.

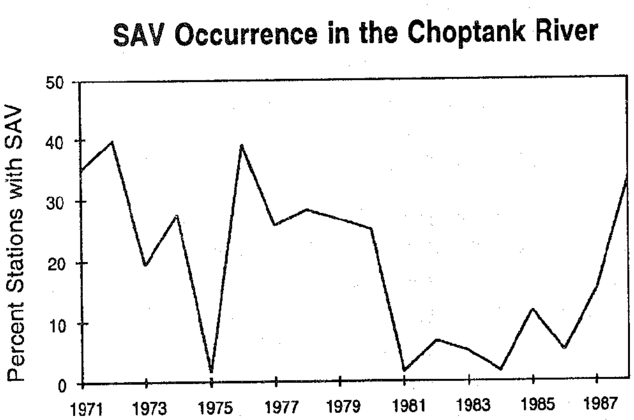

Figure V-74. Percent of Maryland Department of Natural Resources SAV Ground Survey Station where SAV was present in the Choptank River; 1971-1988.

be critical to SAV survival—light attenuation coefficient, total suspended solids, chlorophyll *a*, dissolved inorganic nitrogen, and dissolved inorganic phosphorus.

Study Area

The Choptank River is among the largest tributary on the eastern shore of the Chesapeake Bay (Figure V-73). In addition to the five dominant SAV species (*R. maritima, P. perfoliatus, P. pectinatus, M. spicatum,* and *Z. palustris*), several others have been occasionally reported including *Z. marina* near the river's mouth and *E. canadensis* and *P. crispus* near the headwaters. In the 1960s, detailed transects by the Maryland Department of Natural Resources (MDNR) revealed that SAV existed as far upriver as Hog Island, where the Easton Wastewater Treatment Plant discharges to the river. In the mid-1970s, SAV declined not only in the vicinity of the plant outfall but also in the lower river where it remained at low levels into the early 1980s.

Shallow water less than 3 m deep composes approximately 25% of the Choptank estuary. In the 1970's, SAV was observed at 3 m depth in Trappe Creek where scuba diving was necessary for sediment sampling (Lipschultz *et al.* 1979). At its peak in the late 1970s, Stevenson and Confer (1978) estimated that 41% or approximately 15,000 hectares of the Choptank River was vegetated with SAV. The historical importance of the Choptank River as an SAV habitat is underscored by comparison of this estimate with the 1990 distribution survey which showed only slightly more than 24,300 hectares of SAV throughout the entire Bay (Orth *et al.* 1991).

Water quality sampling stations were selected to span sites where SAV now exist, SAV once existed, and sites that were documented (through seed core analysis) as never supporting SAV historically (G. Bush, personal communication). Stations were located in potential SAV habitats which are characteristically shallow, protected areas. All sites were located in shallow (<2 m depth) nearshore areas, primarily in protected coves in the lower estuary and adjacent to the shoreline in the upper estuary where coves are lacking.

Several wastewater treatment plants discharge effluent into the Choptank River. Although treatment plant discharges are well under 1 million gallons a day (MGD) in the upstream communities of Denton and Greensboro, the combined discharges from Cambridge and Easton exceed 5.75 MGD. Previous studies of nutrient inputs to the Choptank have identified nonpoint sources as the dominant source of nitrogen and phosphorus, contributing 70-90% and 50-80% of nitrogen and phosphorus, respectively (Lomax and Stevenson 1982; Fisher 1988). Thus, nutrient inputs and transport increase significantly during periods of high freshwater discharge.

Table V-11. Choptank River SAV Habitat Monitoring Stations.

STATION NAME	RIVER KILOMETER	LATITUDE	LONGITUDE
Cook's Cove	8.4	38°36'48"	76°16'28"
Todd's Cove	11.1	38°37'05"	76°13'41"
Chapel Creek	15.8	38°36'24"	76°12'27"
Irish Creek	16.7	38°42'24"	76°12'54"
Foxhole Creek	18.5	38°40'32"	76°11'56"
Boone Creek	20.4	38°40'08"	76°10'05"
Trappe Creek	25.9	38°37'49"	76°07'08"
Horn Point	27.8	38°35'58"	76°08'02"
Dickinson Bay	28.7	38°37'24"	76°05'36"
Bolingbrook Creek	37.1	38°35'16"	76°02'17"
Warwick Creek	47.2	38°36'32"	75°58'29"
Windy Hill	54.7	38°41'05"	75°58'32"
Hog Island	63.0	38°44'04"	75°59'59"
Kingston Landing	70.4	38°46'47"	75°57'51"
Gilpin Point	77.8	38°48'43"	75°53'16"
Tuckahoe Creek	81.5	38°52'51"	75°56'42"

From the 1970s data, Heinle *et al.* (1980) characterized the water quality as fair at the mouth of the Choptank and the adjacent mainstem. A fair designation indicates moderate enrichment of nutrients and occasionally high chlorophyll *a* levels. North, into the upper Choptank River (above Hunting Creek to the Delaware state line) and Tuckahoe Creek, water quality is increasingly affected by nonpoint sources as the dilution potential of the river decreases (Ward and Twilley 1986). In this section of the river, high turbidity and chlorophyll *a* levels are usually found. The 1975 mean concentrations of chlorophyll *a* in this section of the river were approximately 75 µg/l (Lomax and Stevenson 1982), a level considered eutrophic compared to concentrations in the lower Choptank River which are an order of magnitude lower during the summer months. The integrity of the lower Choptank River is protected by a 7 m deep sill at the mouth which reduces the probability of deep water intrusions from the mainstem Bay's hypoxic bottom water in the summer (Sanford and Boicourt 1990).

Methods

SAV Distribution

The distribution of SAV over the range of sampling stations (Figure V-73 and Table V-11) was recorded during each growing season from 1985-1989 and compared with the results from the annual SAV ground survey conducted by MDNR (Figure V-74). In addition, aerial photographs (taken through the annual Bay SAV aerial survey program) and oblique aerial photographs of selected portions of the river's shallows (taken with a low flying aircraft) were also used to determine SAV distributions.

Transplant Experiments

Experimental transplanting of SAV ensured that a sufficient number of propagules were available to establish viable populations along the estuarine gradient. To transplant the SAV, plugs of sediment containing living plants (*R. maritima, P. perfoliatus,* and *P. pectinatus)* were extracted from the brackish ponds at the HPEL and placed into 4 inch pots. SAV was planted 1 m apart on 11 x 11 m grids. The corners were marked with wooden stakes so that survival could be determined in later years. Transplanting took place in the spring and early summer months of 1985 to 1987 at Chapel Creek, Horn Point, Irish Creek, Foxhole Creek, Boone Creek, Dickinson Bay, Bolingbroke Creek, Todd's Cove, and Warwick Creek (Figure V-73).

Seasonal Patterns of SAV Biomass

In order to determine what months SAV were sensitive to changes in water quality in the Choptank River, it was necessary to determine when SAV was present during the growing season. The temporal biomass variability in natural populations was determined by analyzing data of sequential SAV harvests collected in 1977 (Stevenson *et al.* in press). These data were compared with those collected in the lower Choptank River and nearby Parsons Island as part of a field program investigating fish distributions (Lubbers *et al.* 1990). The first series of samplings in 1977 were especially useful because, both below and above ground biomass were determined to obtain a total standing stock. These were used to understand the seasonal dynamics of productivity in the Choptank River before the extensive decline in the early 1980s.

Water Quality Monitoring

A series of monitoring stations were located along the Choptank River from near the mouth to a location in Tuckahoe Creek approximately 80 km upstream (Figure V-73 and Table V-11). These stations were placed in historical and potential areas of SAV habitat along the river's margins at water depths ≤3 m. Stations in the lower part of the river were in protected coves while those in the upper river (where coves are lacking) were located in the shallow areas adjacent to shore. All stations were sampled on a monthly basis with cruises every other month during the winter when access was often restricted by ice.

A 0.5-1.0 liter subsurface water sample was collected at approximately 0.1 m below the surface at each station. The sample was immediately placed on ice and held for later analysis of nitrogen, phosphorus, total suspended solids, salinity (Reichert model 10419 refractometer), and conductance (YSI model 34 conductance-resistance meter). A 40-60 ml aliquot was filtered through a Whatman GFC glass fiber filter on site. Both filtrate and filter were placed in ice in the dark and then frozen upon return to the lab for later analysis of nitrite, nitrate, ammonium, dissolved inorganic phosphorus, and chlorophyll *a*. Dissolved oxygen and temperature were measured in the field with a Nestor portable DO meter (Model 8500) equipped with a field probe. A Beckman pH meter with a gel-filled combination electrode was used to measure pH in the field. Light attenuation coefficient was determined by measuring photosynthetically active radiation at depths of 1-2 cm and 1.0 m below the surface with a LICOR LI-1000 datalogger equipped with a LI-1925A underwater quantum sensor.

Chlorophyll *a* concentrations were determined fluorometrically (Standard Methods 1985) on a Turner model 111 fluorometer immediately after grinding in cold 90% acetone. A modified gravimetric determination (Banse *et al.* 1963) was used to measure total suspended solids. Samples were filtered through prewashed and precombusted Whatman GFC filters in a muffle furnace at 450 °C for 1 hour. They were then dried at 60 °C for at least 24 hours prior to being reweighed. Filters were subsequently combusted on a Control Equipment Corporation modified Elmer 240B C-H-N analyzer for particulate carbon and nitrogen determination.

All dissolved nutrients were analyzed on a Technicon AutoAnalyzer II. Total nitrogen and phosphorus were determined as nitrate and dissolved inorganic phosphorus, respectively, following persulfate digestion (Valderrama 1981). Nitrate, nitrite, and dissolved inorganic phosphorus were determined using Harbor Branch modifications (Zimmerman *et al.* 1987) of Standard Methods (1985) techniques; whereas, ammonium was determined using the Whitledge (1981) modification of the Standard Methods (1985) technique.

Results

Transplant Experiments

The transplant plots were highly successful downstream in the Choptank River but were adversely affected by water quality in the upstream sites. The most resilient transplant species was *R. maritima* followed by *P. pectinatus* and *P. perfoliatus*. The *R. maritima* plots (Chapel Creek, Irish Creek, Foxhole Creek, and Boone Creek), located toward the mouth of the Choptank River in 1985 and 1986, had plants in them throughout the growing seasons in which they were planted and were surviving in the following growing season. The *P. perfoliatus* plots did not have any plants surviving at the end of the first growing seasons. The *R. maritima* plots planted in Bolingbroke Creek, Warwick Creek, Horn Point, and Lake's Cove also lost all of their plants by the end of the first season. However, plots planted in Dickinson Bay in 1987 had surviving *P. pectinatus* at the end of the first season, and a few scattered plants were found the next year.

Natural revegetation at the downstream *R. maritima* transplant sites often made it difficult to determine whether plants which grew in the plots during the subsequent growing season had originated from the transplants. There was a notable exception. *P. pectinatus*, planted in Dickinson Bay in 1987, was not growing in the area at the time, so the 1988 regrowth most likely originated from transplants.

In summary, transplanting is a useful tool for evaluating the water quality suitability at a site for SAV growth. The response of these plants within a single growing season to existing conditions confirmed the apparent relationship between SAV distribution and water quality in the Choptank River. In addition, the failure of plots in areas of poor and marginal water quality demonstrated that water quality, not a lack of propagules, was the major inhibiting factor.

Growing Season Determination

The pattern of biomass accumulation for three SAV species in the Choptank River (Figure V-75) reveals that growth is well established by June and persists through October after which the plant dies back. Since Lubbers *et al.* (1990) established that *R. maritima* growth begins in May, the growing season is defined as the six-month period from May to October. Water quality measurements were averaged and medians determined for that period for each year of the study. These median values were compared with the spatial distribution of SAV during the 1986-1988 recolonization in the Choptank. A range of values was then identified for each water quality parameter which corresponded with the persistent to fluctuating SAV growth.

Water Quality Parameters

Temperature

Seasonal temperatures ranged from a low of 2 °C during winter months to 30 °C in the summer. Interannual variations in temperature patterns were minimal from 1986 to 1989 (Figure V-76). Upstream/downstream differences on each sampling date were small, causing vertical isotherms on the contour plot of distance versus time.

Biomass Distribution at Todd's Cove and Todd's Point

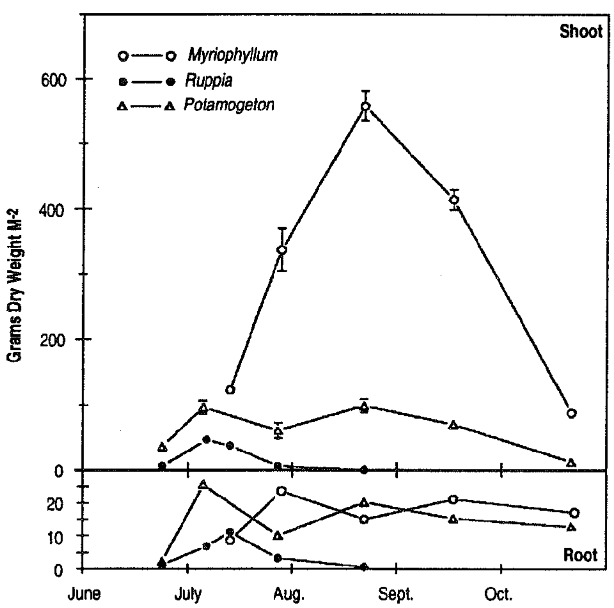

Figure V-75. Biomass distribution over the growing season for three SAV species at Todd's Cove and Todd's Point.

Salinity

Compared to 1989, large incursions in salinity occurred during the dry years of 1986-1988 (Figure V-77). In these three years, elevated salinities occurred not only in the Choptank but also in Tuckahoe Creek which is usually entirely fresh water–albeit tidally influenced. Occasionally, salinities in the range of 3 ppt were found on summer cruises in Tuckahoe Creek (river km in Figure V-78). In winter months, freshwater was typically first encountered upstream at Kingston Landing, as Ward and Twilley (1986) found. However, the waters of 1 ppt can reach downstream below Windy Hill (50 km above the river mouth) as it did in 1989.

Light Attenuation

High total suspended solids and chlorophyll *a* concentrations resulted in high light attenuation coefficients in terms of photosynthetically active radiation. Previous experiments and field monitoring (see Kemp *et al.* unpublished 1981 EPA data report; Wetzel and Penhale 1983 for complete discussion) suggest that light attenuation coefficient values of ≥ 1.75-2 m^{-1} inhibit photosynthesis in all but the shallowest estuarine waters (<0.5 m deep). At 40 km above the mouth of the Choptank River, light attenuation coefficient values of ≥ 2 m^{-1} are common (Figure V-79). Extreme values above 5 m^{-1} were encountered several times at the head of the estuarine portion of the Choptank River and Tuckahoe Creek. During the dry years of 1986-1988, light attenuation coefficient values were <2.0 m^{-1} between river km 20 and 40 where SAV growth was fluctuating, and <1.5 m^{-1} downstream of river km 20 where SAV recolonization was extensive. In comparison, during the 1989 growing season when SAV growth was severely reduced, light attenuation coefficient values exceeded 1.5 m^{-1} down to river km 18. This area was well within the zone which had previously supported persistent SAV. Light attenuation coefficients of <1.5 m^{-1} corresponded with persistent SAV growth and levels <2.0 m^{-1} corresponded with fluctuating SAV growth.

Total Suspended Solids

Elevated total suspended solids concentrations, sometimes exceeding 50 mg/l, routinely occurred over 50 km upstream from the Choptank River mouth between 1986-1989 (Figure V-80). Substantially higher peaks of 80 mg/l were reported for this area of the estuary during the strong 1983 spring freshet (Ward and Twilley 1986). Concentrations below river km 40 (the approximate limit of SAV recolonization) remained below 15 mg/l during most of the growing season, except during occasional wind events which result in resuspension.

Choptank River 1986-1990

Water Temperature

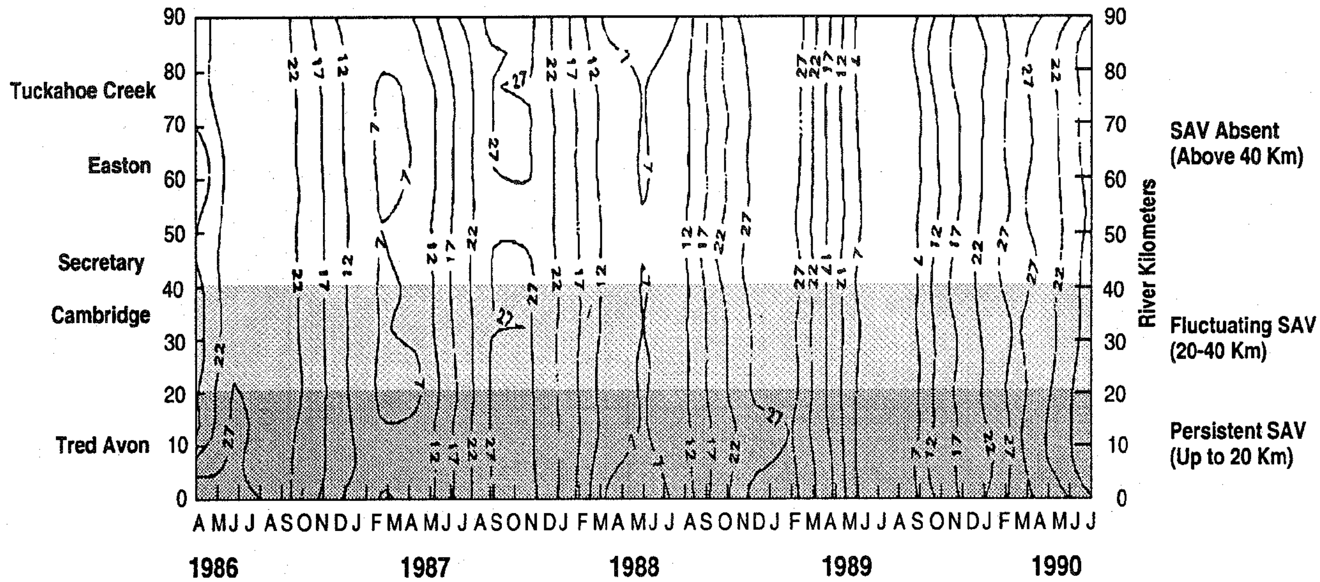

Figure V-76. Water temperature (°C) in the Choptank River displayed by river kilometer over time.

Choptank River 1986-1990

Salinity

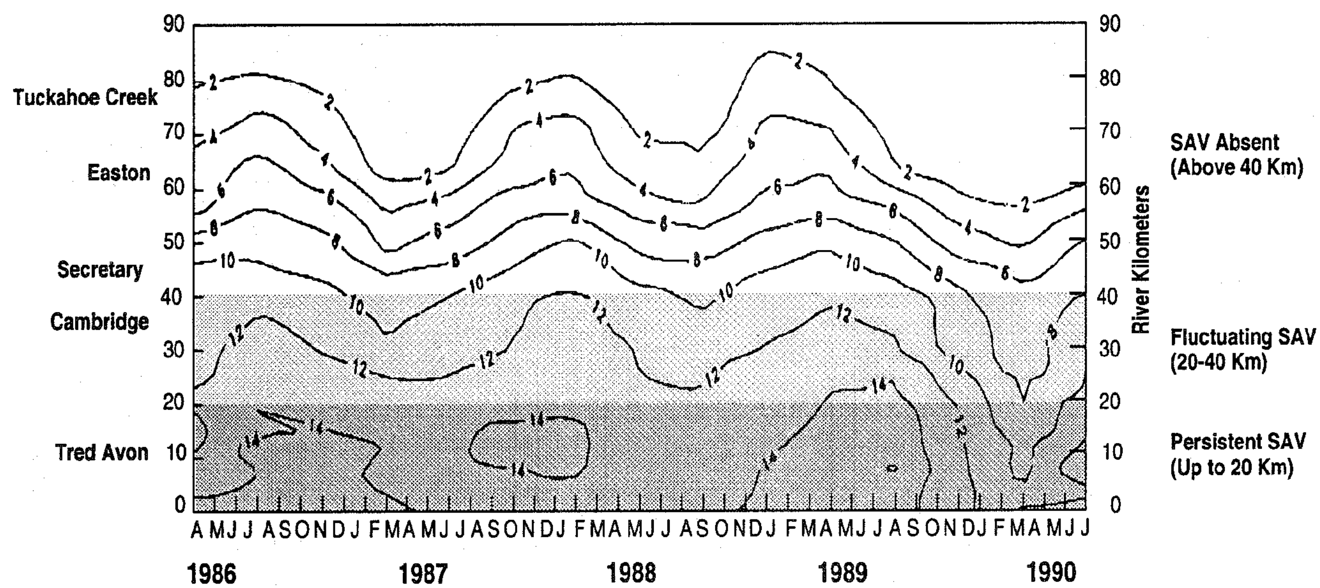

Figure V-77. Salinity (ppt) in the Choptank River displayed by river kilometer over time.

Choptank River 1986-1990

Light Attenuation

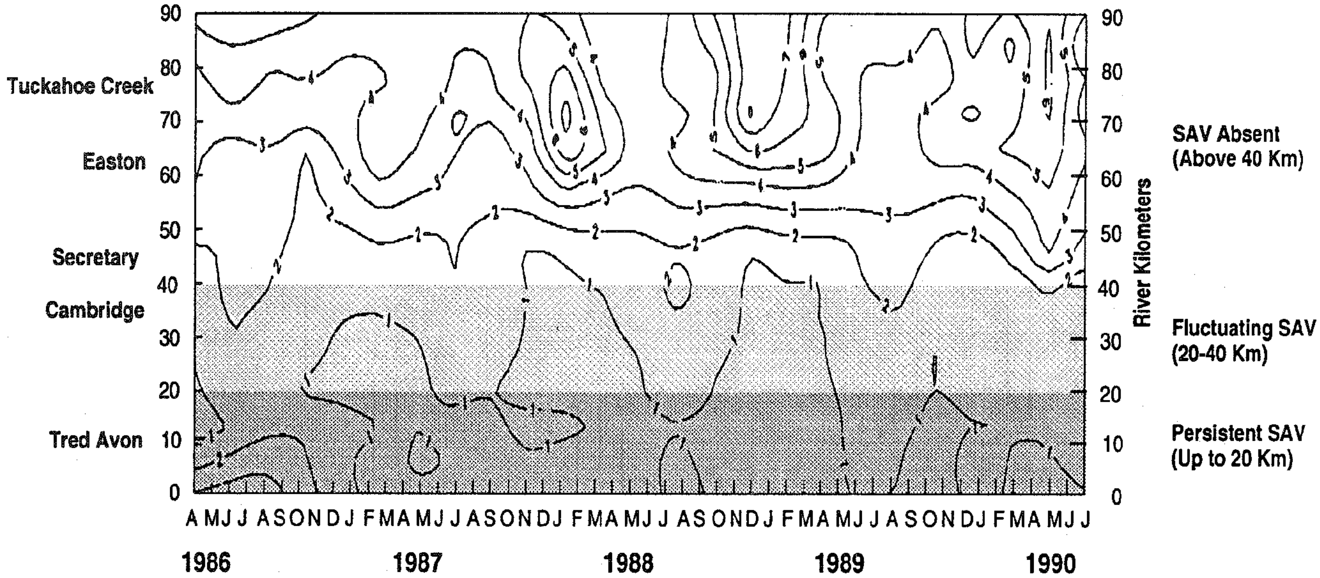

Figure V-79. Light attenuation coefficient values (m^{-1}) in the Choptank River displayed by river kilometer over time.

Choptank River 1986-1990

Total Suspended Solids

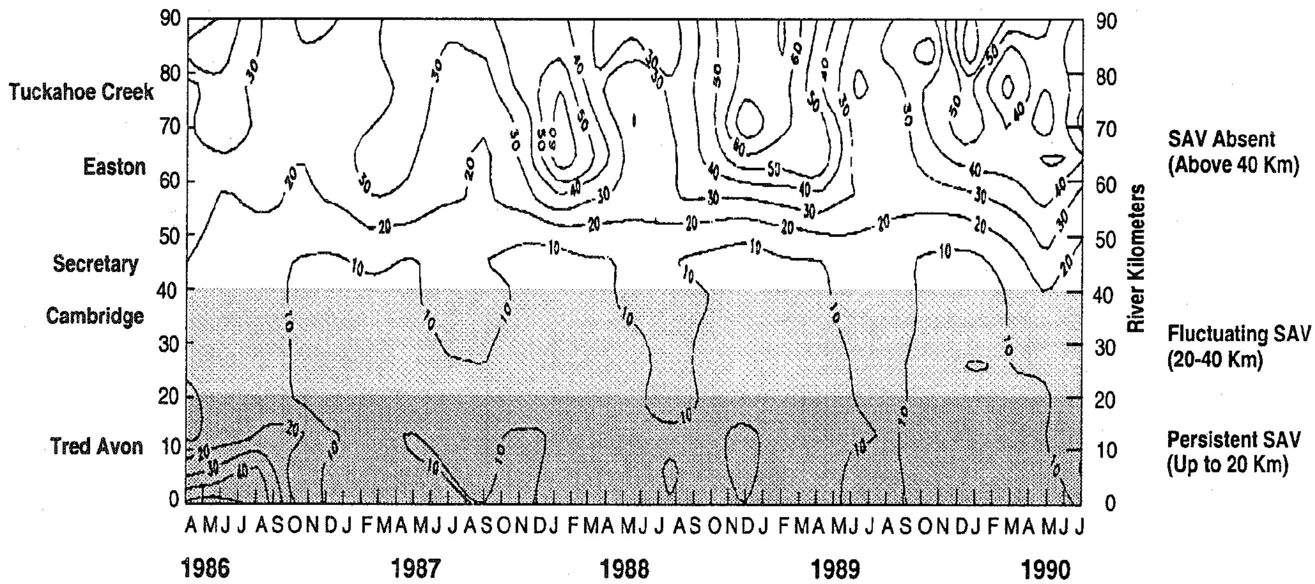

Figure V-80. Total suspended solid concentrations (mg/l) in the Choptank River displayed by river kilometer over time.

Increases in total suspended solids coincided with periods of high freshwater discharge, dramatizing the marked difference that runoff can make in this estuary. Elevated total suspended solids peaks during wet years caused severe limitation of the light available for primary production in both the water and at the benthic boundary layer. Contrary to the conclusions of Yarbro *et al.* (1983), the multi-year data set for the Choptank River suggests that tidal resuspension of sediments is less a factor in influencing average total suspended solids than overall runoff. The difference in perspective between the two studies may be due to the fact that results reported here went on for several years and included major runoff events.

Chlorophyll a

Downriver (river km 0-20), growing season median chlorophyll *a* concentrations were low during the years of lowest precipitation from 1986 to 1988 and increased in 1989, the wettest year of the study period (Figure V-81). Where SAV growth was persistently weak, late winter plankton blooms occurred (> 5 µg/l); however, the highest chlorophyll *a* value of 10 µg/l occurred in August (Figure V-82). Average downriver growing season concentrations (up to river km 40) ranged from 6 µg/l in 1988 to 11 µg/l in 1989. Upriver (river km > 40), growing season median chlorophyll *a* concentrations were higher than downriver concentrations. Further upstream, chlorophyll *a* concentrations increased substantially past Hog Island (river km 63). Growing season medians in the upper Choptank (where SAV was absent) ranged from 17 to 20 µg/l with individual values running as high as 32 µg/l. Peak concentrations of 50 µg/l occurred late in the growing season (Figure V-82). Based on these ranges, 15 µg/l appeared to be the critical chlorophyll *a* concentration below which SAV survived and propagated.

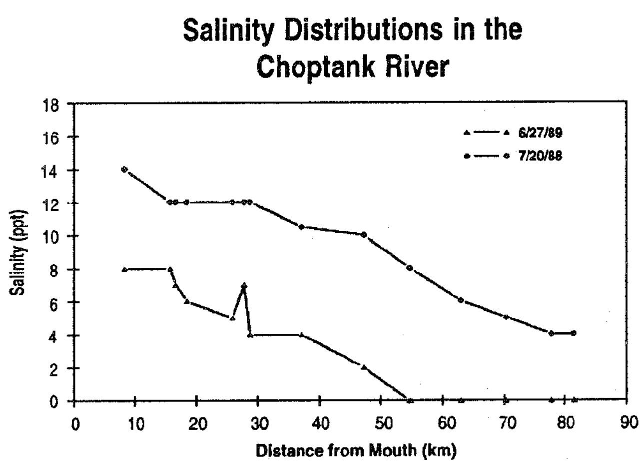

Figure V-78. Salinity distributions in the Choptank River during 7/20/88 and 6/27/89 cruises.

Dissolved Inorganic Nitrogen

Dissolved inorganic nitrogen comprises the largest pool of nitrogen in the water column and was used to characterize the habitat requirements of SAV. In the Choptank River, this form of nitrogen varies significantly with the freshwater discharge entering the river. Peak concentrations occur during high runoff periods; therefore, high dissolved inorganic nitrogen concentrations usually occur in winter and spring when both runoff peaks and uptake in the estuary are lowest. High precipitation during the growing season can also produce elevated concentrations and may be the cause of annual variations in SAV distributions.

Above river km 40, where SAV had not grown during the study period, growing season median dissolved inorganic nitrogen concentrations ranged from 0.15 to 0.26 mg/l during the dry years of 1986 to 1988 (Figure V-83). With the increase in freshwater discharge in 1989, dissolved inorganic nitrogen concentrations averaged 1.12 mg/l in this section of the river. During these same time periods, growing season median concentrations below river km 40 were 0.06 to 0.07 mg/l and 0.23 mg/l, respectively. Based on these data, growing season median dissolved inorganic nitrogen concentrations <0.15 mg/l ensured continued survival and propagation of SAV in the Choptank River. In 1989, when growing season median dissolved inorganic nitrogen concentrations in the lower Choptank exceeded 0.15 mg/l, SAV populations were dramatically reduced from levels observed in the previous three years.

The predominant component of dissolved inorganic nitrogen in the Choptank is nitrate which is typically flushed during the winter from surrounding agricultural fields in the watershed (Lomax and Stevenson 1982; Stevenson *et al.* In Press). By summer, nitrate concentrations fall two orders of magnitude (Figure V-84). This decline reflects both lower nonpoint source inputs as well as losses through denitrification as the temperature of shallow water sediments increases (Shenton-Leonard 1982). For much of the growing season, nitrate levels were well below 0.21 mg/l throughout the estuary.

Dissolved Inorganic Phosphorus

During the SAV growing season, dissolved inorganic phosphorus concentrations ranged from 0.03-0.04 mg/l above the upriver extent of SAV growth (Figure V-85). Below river km 40 where SAV growth was fluctuating to persistent, average dissolved inorganic phosphorus concentrations were 0.005 to 0.009 mg/l, indicating 0.01 mg/l as the critical concentration for SAV growth.

During the summer, distinct dissolved inorganic phosphorus peaks (Figure V-85) occurred from river km 54 to km 62. The Easton Wastewater Treatment Plant appears to be the primary source of dissolved inorganic phosphorus in this region of the river, although this area could also be a focal point for phosphorus recycling from the sediments. Ward and Twilley (1986) did not detect any distinct dissolved inorganic phosphorus pattern, but their study was conducted in a year which included a high rainfall spring with a large freshet. The three dry years of this study showed the impact of the wastewater treatment plant outfalls on water column concentrations without being obscured by strong nonpoint source background noise (Figure V-86). The total phosphorus loads from the Easton Plant have remained relatively constant through the summer of 1988 (Figure V-87). Subsequent data suggests large reductions of phosphorus in the river in 1989 and 1990 (Stevenson *et al.* in prep).

Nitrogen:Phosphorus Ratios

Nitrogen to phosphorus ratios reflect the pronounced gradients in the two major nutrients and indicate a wide range of variability. Peak total nitrogen to total phosphorus (Figure V-88) and dissolved inorganic nitrogen to dissolved inorganic phosphorus ratios (Figure V-89) occur when freshwater inputs are high. The ratios decline markedly during the summer. The dissolved inorganic nitrogen to dissolved inorganic phosphorus ratios clearly show the influence of the Easton Wastewater Treatment Plant discharge especially during the growing season (Figure V-89). Higher ratios of the most available forms of nitrogen and phosphorus occur both above and below the outfall at river km 63. A dissolved inorganic nitrogen to dissolved inorganic phosphorus ratio over 100, measured near the mouth of the Choptank River in August 1988, reflects a high ammonia concentration resulting from an intrusion of ammonia-rich bottom water from the mainstem of the Bay (Sanford and Boicourt 1990).

The low total nitrogen to phosphorus ratio (Figure V-88) suggests that enough phosphorus enters the water column (possibly through sedimentary regeneration pathways) to cause nitrogen limitation throughout the estuarine gradient in dry years when SAV is abundant. In average precipitation years, when SAV is less abundant, higher nitrogen to phosphorus ratios suggest that phosphorus is limiting especially in the lower river.

Summary and Conclusions

SAV habitat requirements were established based on correspondences between existing distributions of SAV, regrowth during the study period, SAV transplant success, and growing season water quality in the mesohaline waters of the Choptank River (Table V-12). Three-dimensional comparisons of total suspended solids, chlorophyll *a*, and light attenuation (Figure V-90) as well as dissolved inorganic nitrogen, dissolved inorganic phosphorus, and light attenuation (Figure V-91) illustrate both the interrelationships between these parameters and the basis for the mesohaline SAV habitat requirements. In summary:

1) Growing season median light attenuation coefficient values <1.5 m^{-1} corresponded with persistent SAV growth.

2) Growing season median total suspended solid concentrations <15 mg/l characterized habitats with persistent SAV growth.

3) Growing season median chlorophyll *a* concentrations <15 µg/l promoted SAV survival and propagation.

4) Growing season median dissolved inorganic nitrogen concentrations <0.15 mg/l corresponded with persistent SAV growth.

5) Growing season median dissolved inorganic phosphorus concentrations <0.01 mg/l corresponded with persistent SAV growth.

York River

Habitat quality requirements for SAV in the polyhaline regions of the Chesapeake Bay were developed by relating the results of a series of studies of the growth and survival of *Z. marina* transplants to water quality parameters at a range of sites in the lower Chesapeake Bay. The sedimentary environment can have an effect on *Z. marina* growth

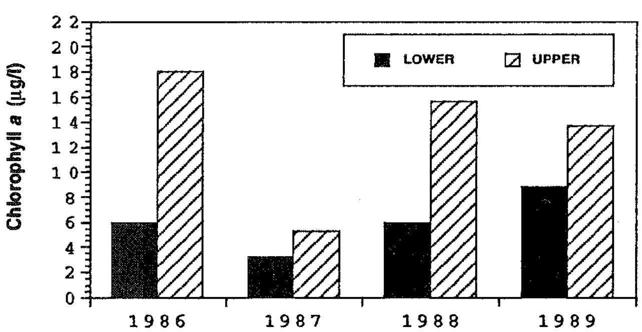

Figure V-81. Lower (river km 0-20) and upper (river km >40) Choptank River chlorophyll *a* May - October medians for 1986-1989. The zone with fluctuating SAV (river km 23-40) was excluded.

and production; however, because this plant declined from areas with such a wide range of sediment types in the Bay, it was judged not to have been a major factor limiting survival and the studies of its effects are not included. The study objectives of the work reported here were to:

1) monitor the water quality characteristics along a gradient of sites that presently or formerly supported SAV;
2) determine the potential for plant production at these sites through transplanting; and,
3) determine the seasonal levels of water quality variables which characterize viable SAV habitat in this region based upon these two sets of information.

Study Area

Station locations selected for this study extend from the mouth of the York River to the former upriver limits of SAV growth (Figure V-92 and Table V-13). Seven stations were sampled over the study period. Guinea Marsh, located at the mouth of the estuary, supports *Z. marina* beds that have decreased only moderately in area since 1971 (Orth *et al.* 1979). Allens Island, 4 km upriver, experienced greater dieback but still supports some vegetation. Gloucester Point, 6 km further upriver, is at the limit of the current distribution of *Z. marina.* There was an almost complete decline of plants in this area by 1974. Since that time, though, they have regrown somewhat from a few remnant patches as well as successful transplant experiments and seed recruitments from downriver vegetated areas. Yorktown, located along the western shore less than 1 km upriver from Gloucester Point, experienced a dieback in several, small *Z. marina* beds, but has had some recruitment of *Ruppia maritima* as well as successful transplants of *Z. marina*. Mumfort Island, Catlett Island, and Claybank are located successively upriver to 27 km from the river's mouth. Extensive beds dominated by *Z. marina* disappeared completely from these sites by 1972 with no regrowth evident since that time despite repeated transplant experiments between 1978 and 1990. All sites are characterized by relatively broad, shallow flats (<2 m mean low water) extending landward from a narrow but much deeper (>10 m mean low water) mid-channel region. Sediments in the shoal areas are principally fine sands.

Methods

<u>Transplant Experiments</u>

Transplants of whole *Z. marina* shoots were used to determine the capacity of sites to support vegetation. Beginning in 1979, transplanting was undertaken in September or October of each year up to the present. Plants were collected from the established bed at Guinea Marsh and transplanted to a range of study sites in the York River. Planting units consisted of 20 cm x 20 cm sods with or without intact sediments or 10 cm diameter plugs or shoots which were washed free of sediments and bundled together in groups of 10 to 15 with a metal twist tie (Fonseca *et al.* 1982, 1985). Vegetation was generally transplanted within 24 hours of removal from the donor site. From 1984 to present, planting units were spaced at 2 m or 0.5 m centers in 5 x 5 arrays replicated 2 to 4 times per site. Survivorship was monitored at monthly to bimonthly intervals until either no plants remained at a site or the planting units had grown together.

Table V-12. SAV habitat requirements for mesohaline habitats in the Choptank River.

Parameter	Habitat Requirement
Light Attenuation Coefficient	$<1.5 m^{-1}$
Total Suspended Solids	<15 mg/l
Chlorophyll *a*	<15 ug/l
Dissolved Inorganic Nitrogen	<0.15 mg/l
Dissolved Inorganic Phosphorus	<0.01 mg/l

Choptank River 1986-1990

Chlorophyll *a*

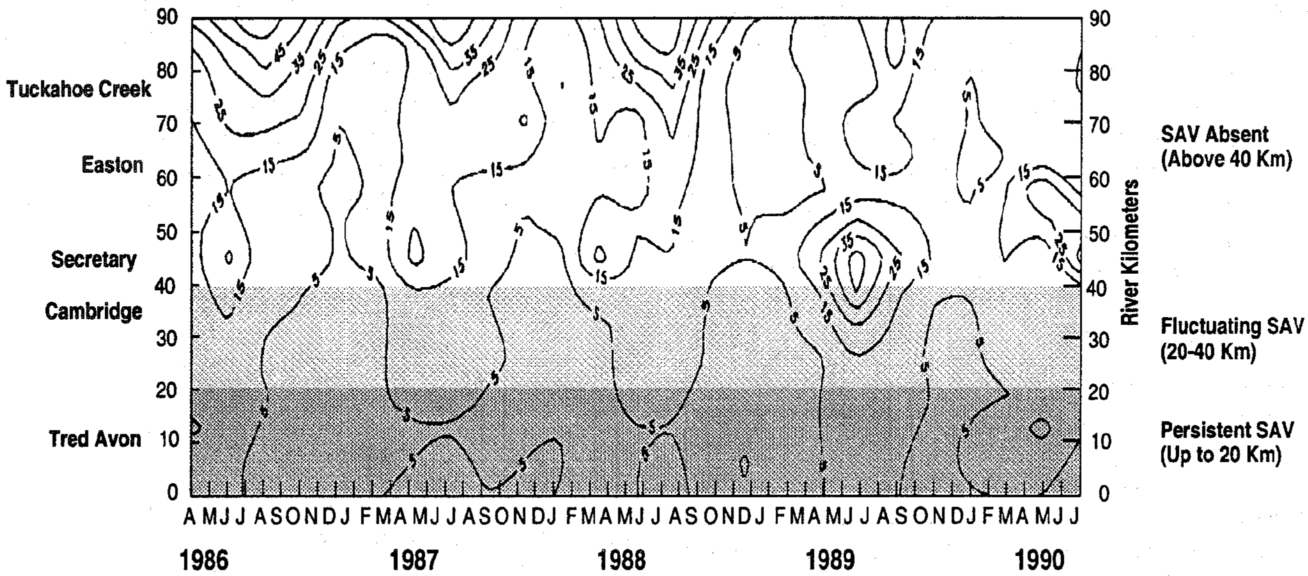

Figure V-82. Chlorophyll *a* concentrations (µg/l) in the Choptank River displayed by river kilometer over time.

Choptank River 1986-1990

Dissolved Inorganic Nitrogen

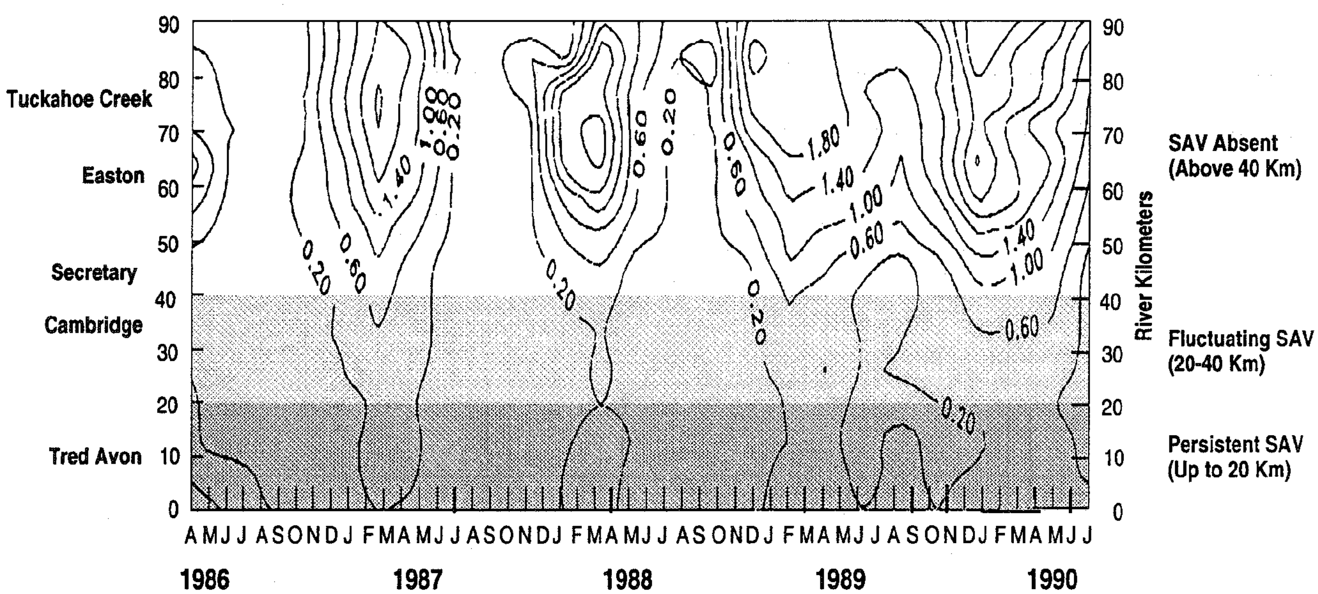

Figure V-83. Dissolved Inorganic nitrogen (mg/l) concentrations in the Choptank River displayed by river kilometer over time.

Choptank River 1986-1990

Nitrate

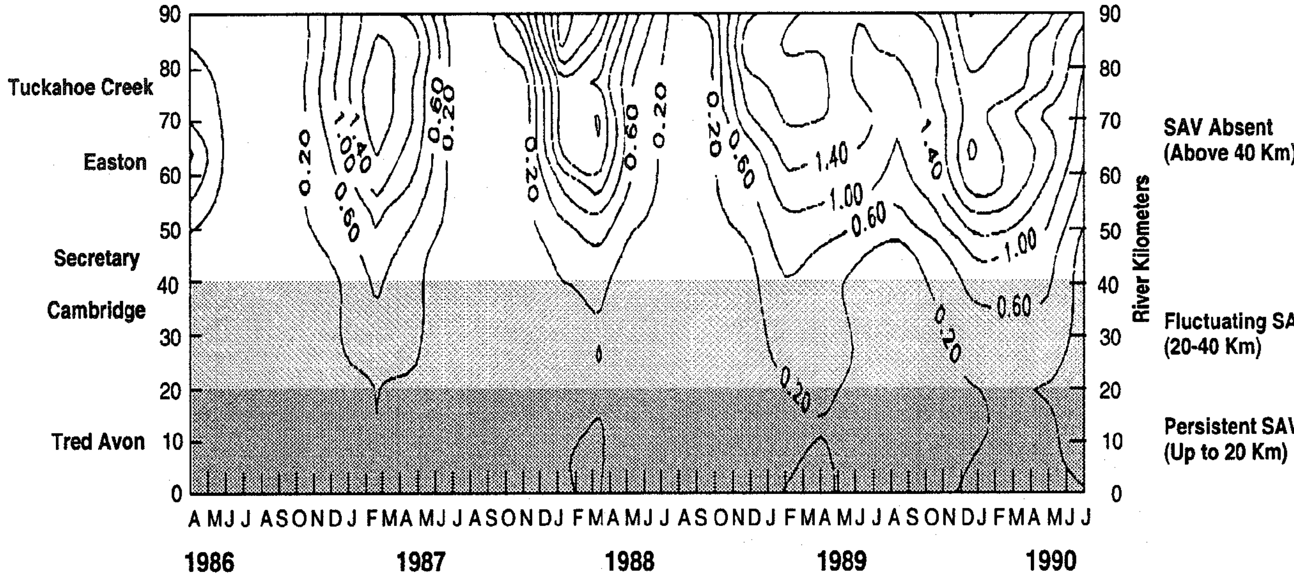

Figure V-84. Nitrate concentrations (mg/l) in the Choptank River displayed by river kilometer over time.

Choptank River 1986-1990

Dissolved Inorganic Phosphorus

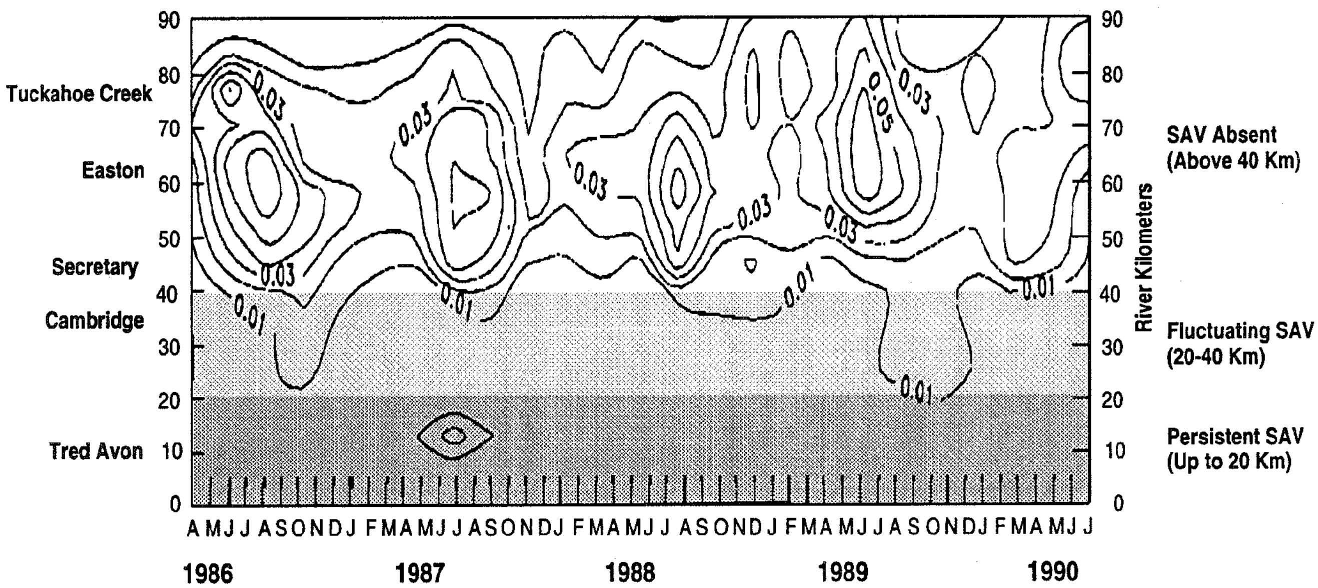

Figure V-85. Dissolved inorganic phosphorus concentrations (mg/l) in the Choptank River displayed by river kilometer over time.

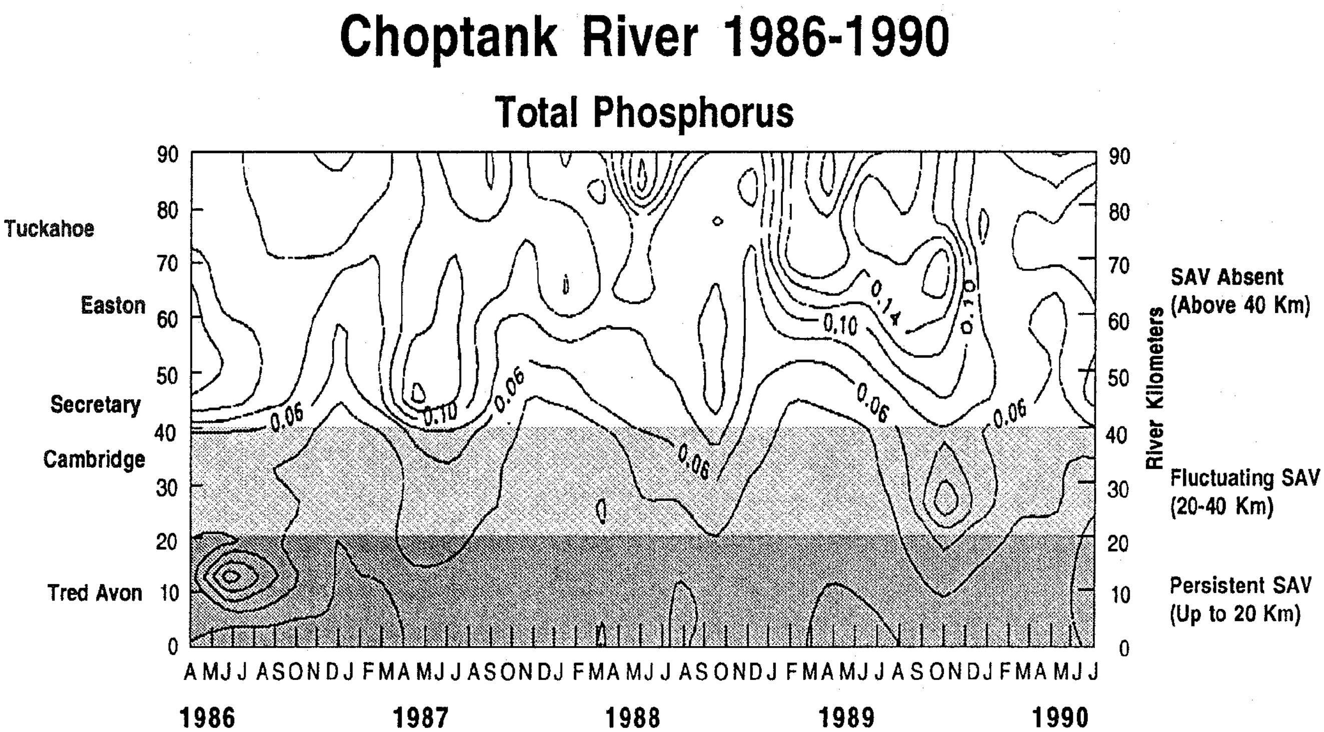

Figure V-86. Total phosphorus concentrations (mg/l) in the Choptank River displayed by river kilometer over time.

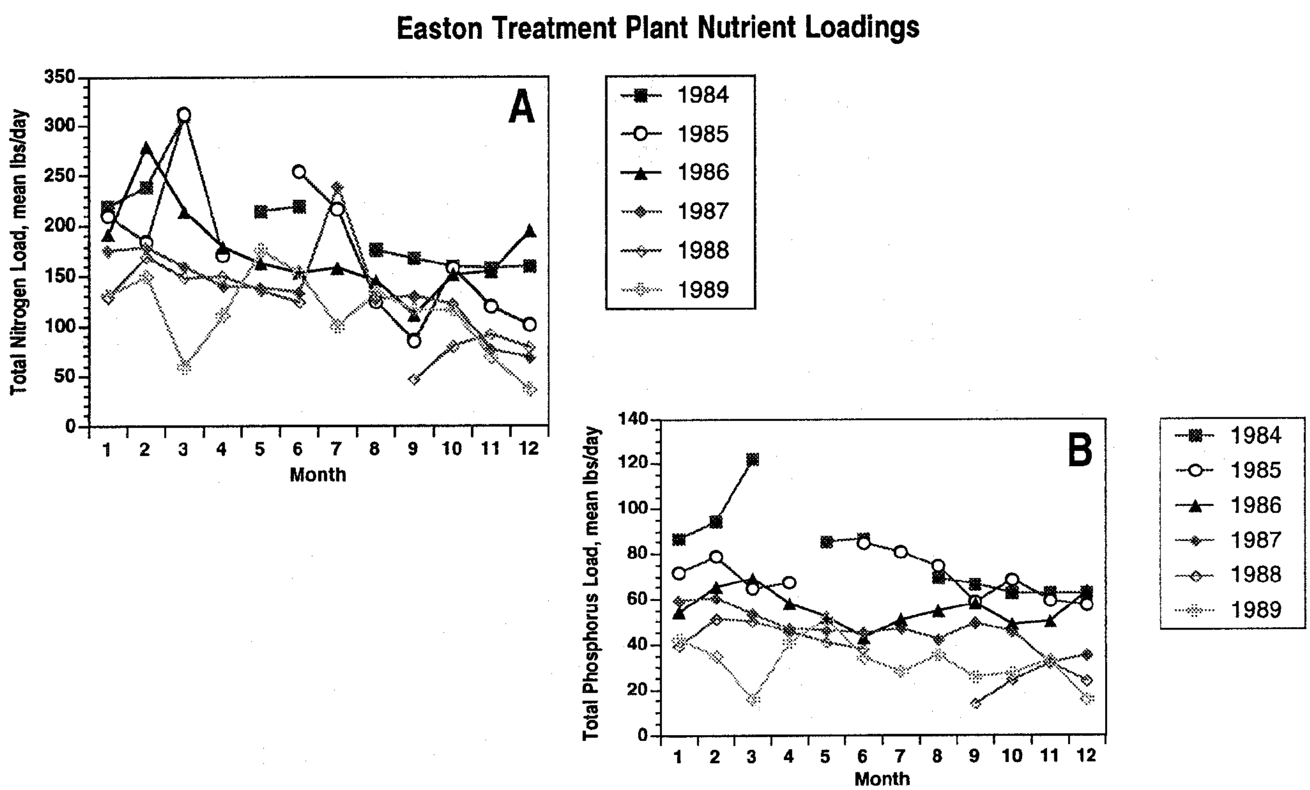

Figure V-87. Total nitrogen (A) and total phosphorus (B) loads from the Easton, Maryland Wastewater Treatment Plant (Data from MDE courtesy of EPA-CBPO).

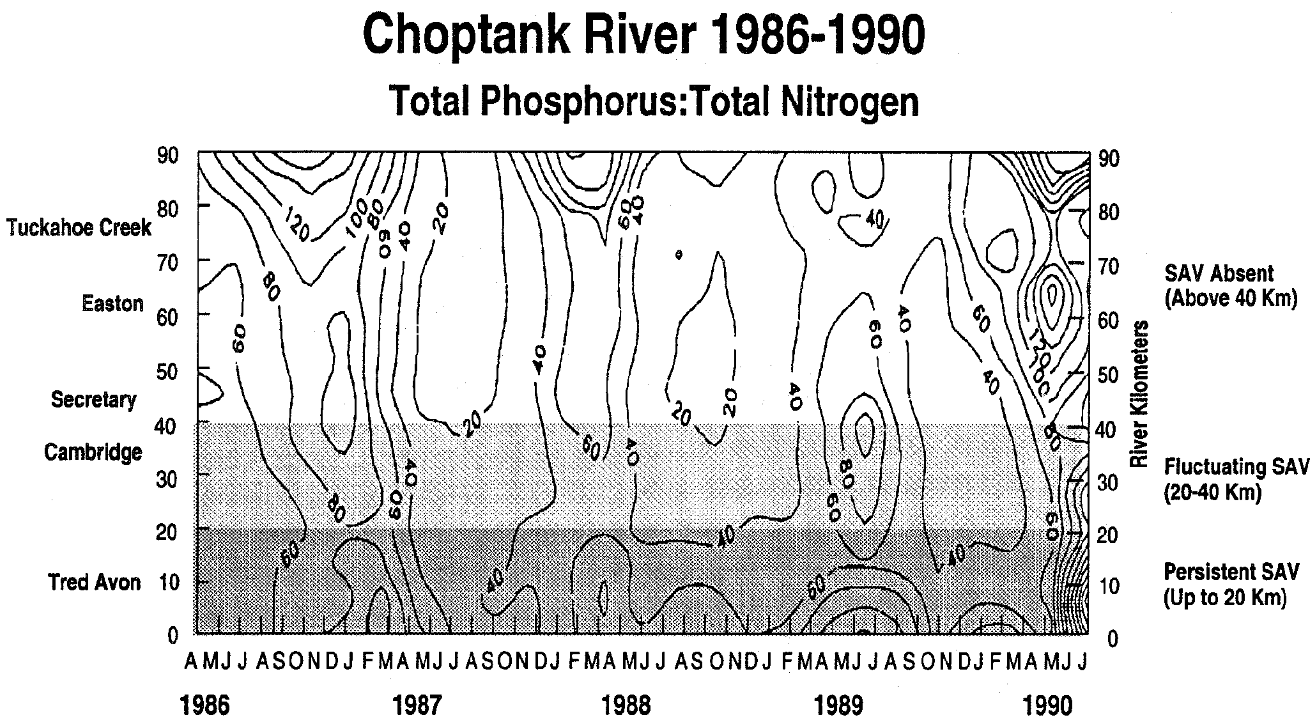

Figure V-88. Total phosphorus to total nitrogen ratios in the Choptank River displayed by river kilometer over time.

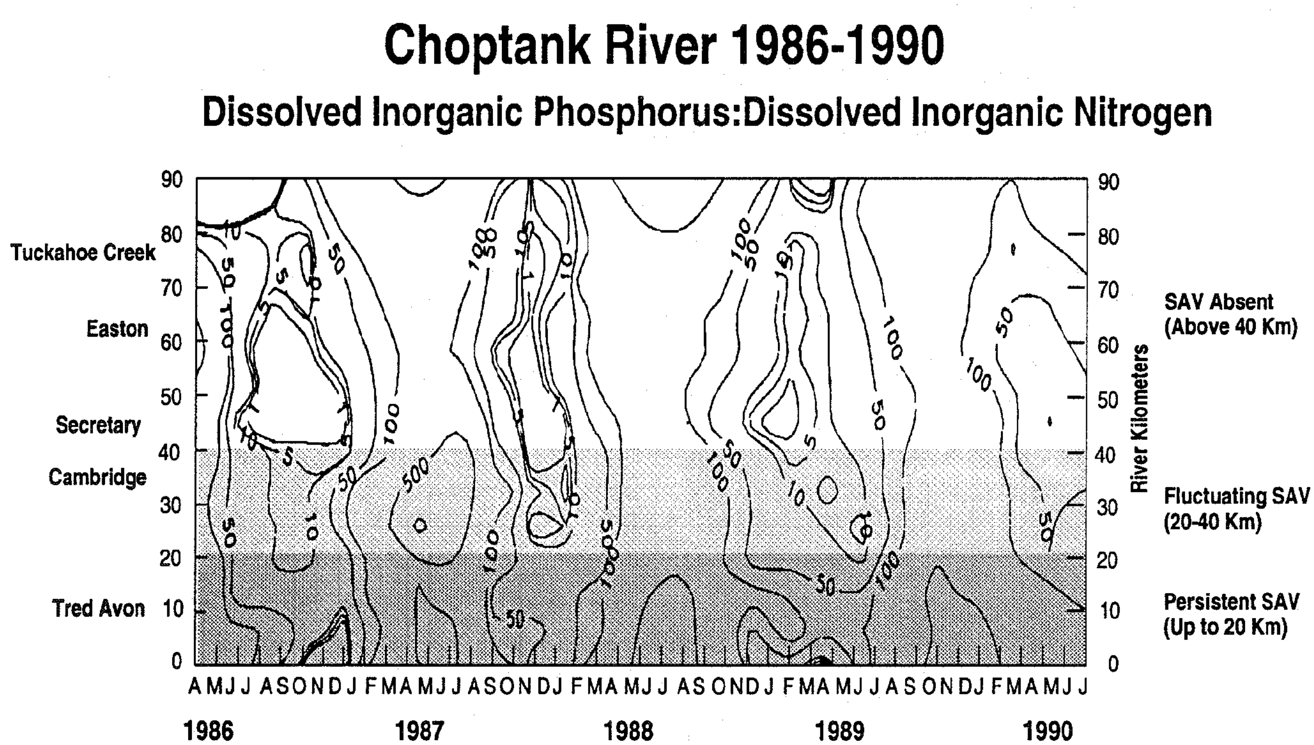

Figure V-89. Dissolved inorganic phosphorus to dissolved inorganic nitrogen ratios in the Choptank River displayed by river kilometer over time.

Total Suspended Solids, Chlorophyll *a*, and Light Attenuation: Choptank River

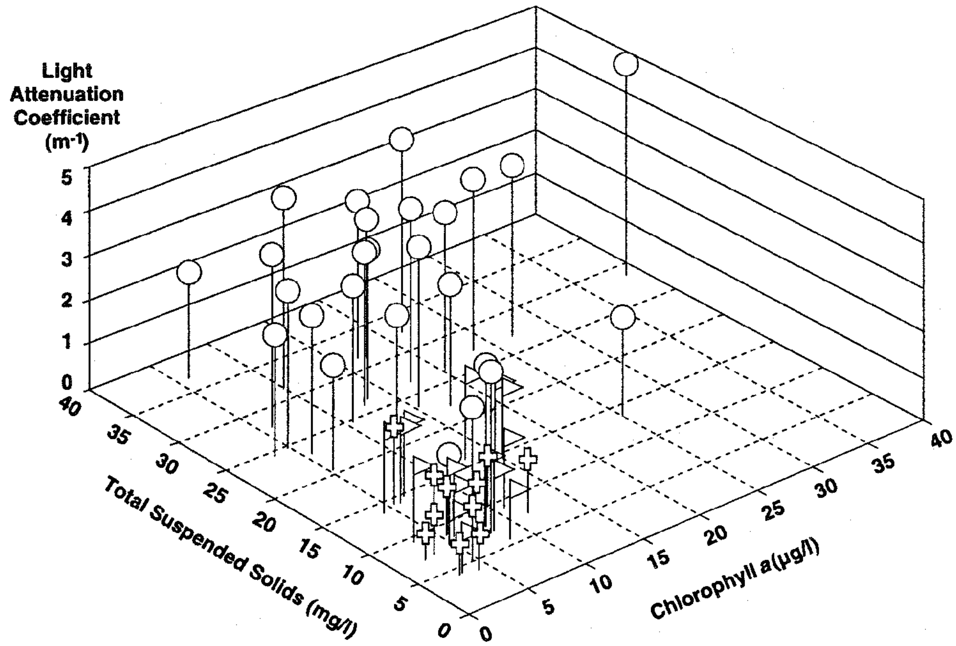

Figure V-90. Three-dimensional comparisons of May-October median light attenuation coefficient, total suspended solids, and chlorophyll *a* concentrations at the Choptank River stations from 1986-1989. Stations and years are plotted separately with SAV status indicated. Plus = persistent SAV; flag = fluctuating SAV; circle = SAV absent.

Dissolved Inorganic Nitrogen, Dissolved Inorganic Phosphorus, and Light Attenuation: Choptank River

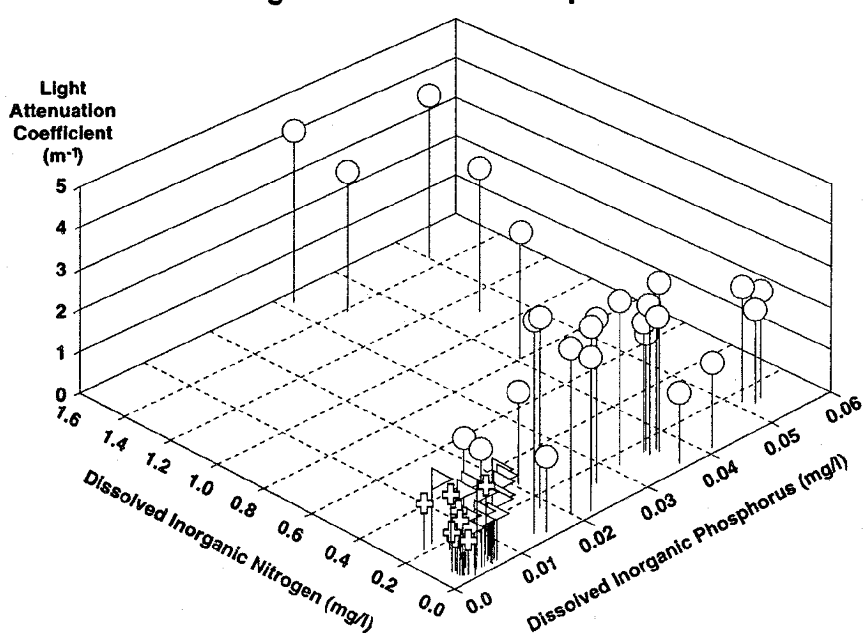

Figure V-91. Three-dimensional comparisons of May-October median light attenuation coefficient, dissolved inorganic nitrogen, and dissolved inorganic phosphorus concentrations at the Choptank River stations from 1986-1989. Stations and years are plotted separately with SAV status indicated. Plus = persistent SAV; flag = fluctuating SAV; circle = SAV absent.

Growth Experiments

Macrophyte growth was studied *in situ* from April 1985 to July 1986, using a modified leaf marking technique (Sand-Jensen 1975). Whole turfs of *Z. marina* (including roots, rhizomes, and undisturbed sediments to a depth of 20 cm) were obtained from a stable grass bed at Guinea Marsh, placed in polyethylene boxes (40 x 60 x 20 cm), and submerged at the upriver Gloucester Point and Claybank sites. After a two-week acclimation period, three 15 cm diameter quadrats were randomly located within each box. Each shoot within each quadrat was tagged with a numbered, monel metal band placed around its base. The youngest leaf was marked with a small notch and the leaf lengths and widths were recorded. The boxes were retrieved at approximately weekly intervals and placed in a seawater bath. The length and width of all leaves on tagged shoots were recorded. The number of new leaves on each shoot was recorded, any new shoots within the quadrats were tagged, and the youngest leaf on all shoots was marked. Thus, individual leaves could be uniquely identified and measured from formation through loss. Dry weight and ash-free weight were estimated from previously derived linear regressions of leaf weight on area. Growth rates and leaf losses were calculated for each marking interval. Using a two-way analysis of variance, the effect of site on various shoot parameters was tested. Residual analysis was used to check the aptness of all models and Bonferroni multiple comparisons were used to locate site differences within sample intervals using a family confidence coefficient of 0.95 (Neter and Wasserman 1974).

Boxes at the sites were disturbed periodically, generally through the burrowing of crabs or fish. Therefore, when excavations occurred in a box at either site, boxes at both sites were replaced with others that had been acclimating at the respective sites for identical periods of time. Using information from the marked plants, rhizome production rates of the Gloucester Point and Claybank transplants were determined between initial transplanting in the fall of 1985 and the summer of 1986. Assuming that average formation of the individual rhizome segments occurred at the same rate as that calculated for leaf production (Sand-Jensen 1975; Jacobs 1979; Aioi *et al.* 1981), the age of each individual rhizome segment was determined for each of the transplant samples obtained in March, May, June, and July 1986. Rhizome production for the intervals between each sampling was then calculated by summing the biomass of rhizome segments produced during that period.

Water Quality Monitoring

Triplicate subsurface (0.25 m) water column samples were taken every two weeks at the shoal sampling sites along the York River. Long-term data are available for the Guinea Marsh, Gloucester Point, Mumfort Island, and Claybank sites. The Allens Island station was dropped in September 1985, as its water quality parameters were similar to Guinea Marsh and Gloucester Point (both characterized by suitable SAV conditions). The Yorktown and Catlett Island stations were added in December 1987 and

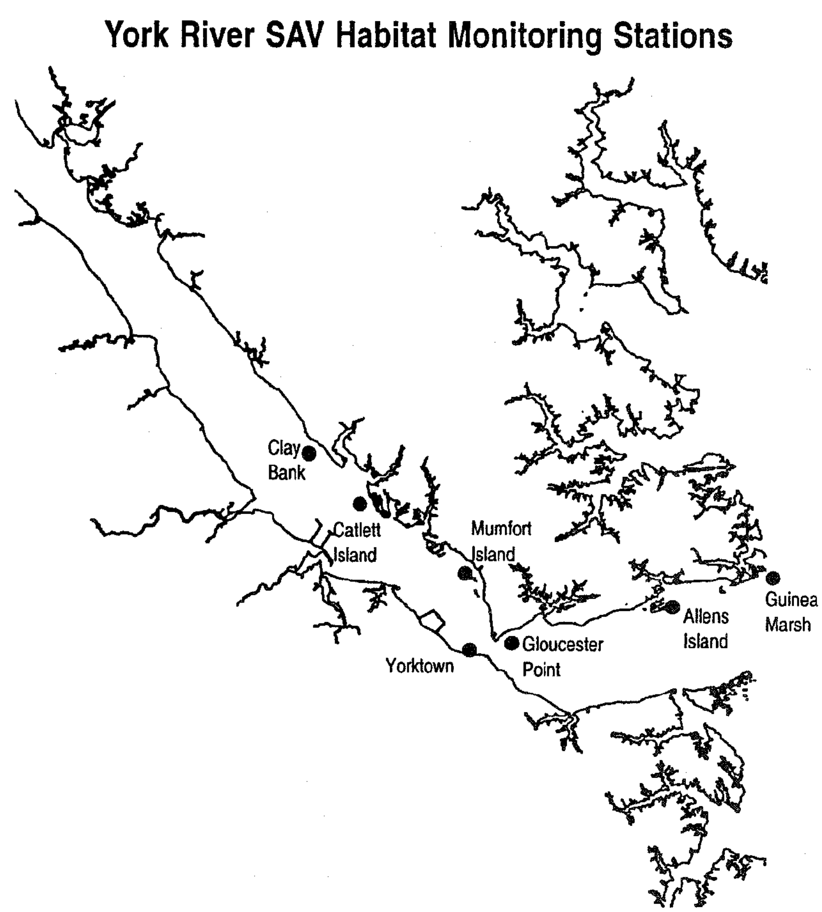

Figure V-92. The seven water quality sampling sites located in the nearshore and potential SAV habitats in the lower York River region.

Table V-13. York River SAV Habitat Monitoring Stations.

STATION NAME	LATITUDE	LONGITUDE
Guinea Marsh	37°15'04"	76°22'59"
Allens Island	37°15'11"	76°25'34"
Gloucester Point	37°14'47"	76°30'09"
Yorktown	37°14'25"	76°30'45"
Mumfort Island	37°15'41"	76°30'42"
Catlett Island	37°18'55"	76°34'05"
Claybank	37°20'53"	76°36'33"

October 1985, respectively, to provide a better measure of the variability associated with the transition from acceptable to unacceptable water quality.

Water quality samples were collected sequentially on the same day, beginning with the most downriver, and stored on ice in the dark for up to four hours. Nitrite, nitrate, and ammonium were determined spectrophotometrically following the methods of Parsons *et al.* (1984); inorganic phosphorus was determined using EPA (1979) methods. Suspended matter was collected on precombusted, Gelman Type A/E glass fiber filters, dried at 55 °C, and ashed at 550 °C for 5 hours. Chlorophyll *a* was collected on Whatman GF/F glass fiber filters, extracted in a solution of acetone, dimethyl sulfoxide (DMSO) and 1% diethylamine (DEA) (45:45:10) following the methods of Shoaf and Lium (1976) as modified by Hayward and Webb (unpublished), and determined fluorometrically. Chlorophyll *a* concentrations were uncorrected for phaeopigments. Salinity was measured with a refractometer or conductivity meter, and temperature was measured by bulb thermometer or thermistor.

Diffuse downwelling attenuation of photosynthetically active radiation (PAR) was determined through water column profiles of photosynthetic photon flux density (PPFD) with a LI-COR, LI-192 underwater cosine corrected sensor. The data were collected concurrently with the water samples. Additionally, underwater PPFD was measured continuously from August 1986 to September 1987 at the Gloucester Point and Claybank stations using arrays of two underwater sensors placed vertically at fixed distances. The sensors were cleaned frequently, and the measured PPFD was corrected for fouling by assuming a linear rate of light reduction due to fouling between cleanings.

The biweekly samples of the water column parameters, obtained during the period of August 1984 to October 1989, were compared using two-way analysis of variance as the main effects were date and site. Bonferroni multiple comparisons were used to test for site differences within sample dates using a family confidence coefficient of 0.95 (Neter and Wasserman 1974).

Results

Transplant Experiments

There have been no successful long-term transplants of *Z. marina* at the Mumfort Island station or upriver sites since 1979. In contrast, the transplants have always been successful at the Gloucester Point station. Transplant survival was reported for *Z. marina*, transplanted in the fall of 1979, after one year at the Guinea Marsh, Allens Island, Gloucester Point, and Mumfort Island stations as 98%, 93%, 82%, and 11%, respectively (Orth and Moore 1982). By the following spring, no shoots remained at Mumfort Island. A similar lack of success occurred with transplant attempts at sites upriver of the Gloucester Point station between 1980 and 1984.

Survival of *Z. marina*, transplanted each fall from 1985 to 1987 at the Gloucester Point and Claybank sites, are presented in Figures V-93 and V-94. Again, as with earlier attempts, plants transplanted at all the sites did well after initial losses due to wave scouring or burrowing of fish and crustaceans. Beginning in the late spring, however, transplants at the stations upriver of Mumfort Island died back with no survival by mid-to-late summer. Although problems associated with high turbidity and other unfavorable conditions resulted in irregular sampling of the transplants during the summer period, the data suggest that the dieback occurred earlier than the more upriver sites. Dead transplants were characterized by masses of blackened rhizomes with no above ground material. In some cases, when transplants were observed immediately prior to complete loss, remaining shoots consisted of only one or two short leaves.

There have been some inter-annual differences observed in the length of survival of transplants immediately upstream of the Gloucester Point station. Prior to 1984, there was limited success in transplanting at the Mumfort Island station with transplants dying out during the summer after fall transplanting (Orth *et al.* 1979). During the 1987-1988 period, however, the transplants survived throughout the summer and into the fall, but by the next summer they disappeared. Although no quantitative data were available for 1986-1987, some living shoots transplanted in the fall of 1986 were observed in the fall of 1987.

In the beginning of 1986, *Z. marina* plants were transplanted at the Yorktown station. Survival at this site (which is along the western shore just downriver from Mumfort Island) has been comparable to Gloucester Point with transplanted beds now established. Since 1986, *R. maritima* recruitment has also been observed.

These data suggest that the relatively short region of the York River in the vicinity of Gloucester Point is a transition zone between acceptable and unacceptable environmental conditions for SAV growth. It is likely, therefore, that differences in these environmental conditions are small and that SAV is growing close to their limits of tolerance, even where it continues to flourish. Very small decreases

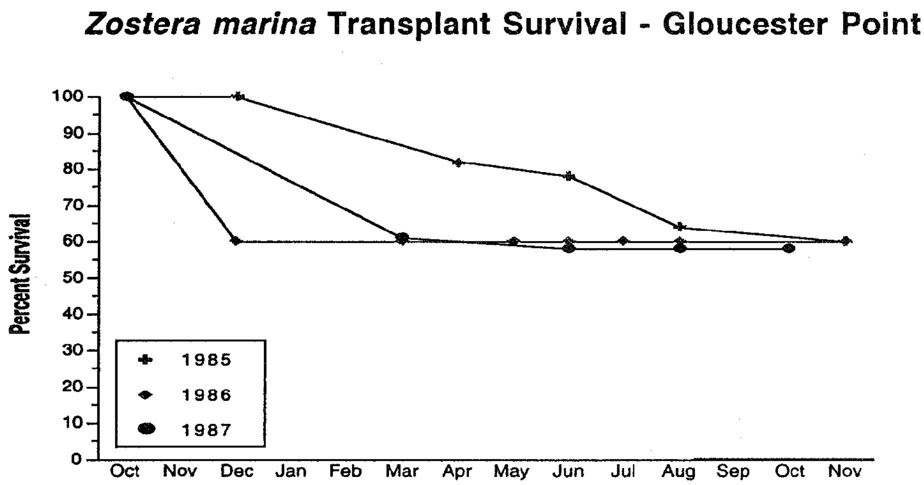

Figure V-93. *Zostera marina* transplant survival at Gloucester Point.

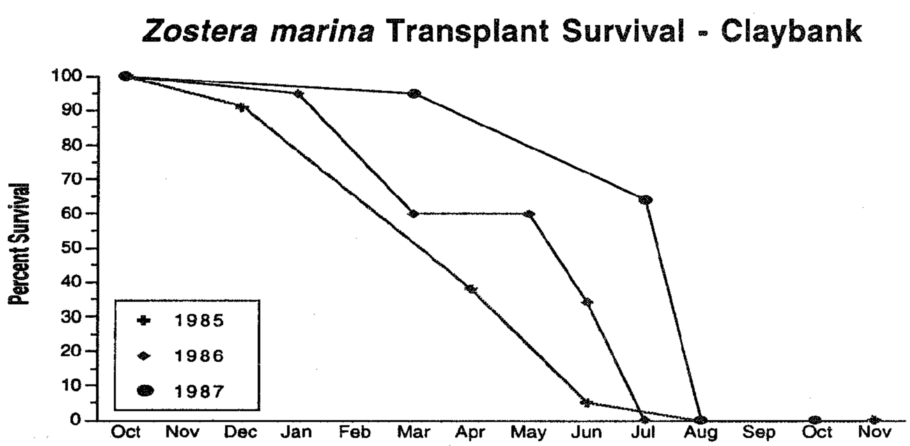

Figure V-94. *Zostera marina* transplant survival at Claybank.

in environmental quality can potentially harm the vegetation. Conversely, small improvements in environmental conditions may likely result in significant increases in SAV populations.

Growth Experiments

A bimodal pattern of above ground growth was observed at the Gloucester Point and Claybank sites, where highest *Z. marina* growth rates occurred each spring and a second period of increased growth occurred in the fall (Figure V-95). Significant differences in growth rates between the sites were observed only during the spring and fall periods ($p<0.05$).

From November until March, production of below ground rhizomes of transplants at the Gloucester Point and Claybank sites was low and comparable ($p<0.05$). Maximum production occurred at both sites between March and May. Production was greatest, however, from March until July (when the Claybank vegetation died back) at Gloucester Point ($p<0.05$).

Determination of Seasons

Characterization of seasonal *Z. marina* growth was determined by relating plant growth to water temperature, thus allowing relationships to be developed between plant response and environmental conditions based upon seasonal growth patterns. To accomplish this, the 0 °C-30 °C and 30 °C-0 °C periods in the annual temperature cycle were treated independently. For each temperature period, unique regressions were fit to both the increasing and decreasing portions of the growth curve using log rate vs. inverse temperature transformations. The two resultant equations for each temperature period were solved for the maximum growth rate and inflection temperature. The temperature cutoffs (at which growth equals 50% of this maximum rate) were determined as follows:

For the 0 °C-30 °C temperature period, the calculated regression equations for the increasing and decreasing portions of the growth curve were:

1) $G=-0.95 + (16.88 \bullet (1/T))$ and
2) $G=0.49 - (6.42 \bullet (1/T))$

where G is the log growth rate, and T is the water temperature.

Therefore, solving simultaneously for G produces

3) $6.42 \bullet G = (6.42 \bullet (-0.95)) + (6.42 \bullet 16.88 \bullet (1/T))$ and
4) $16.88 \bullet G = (16.88 \bullet (0.49)) - (16.88 \bullet 6.42 \bullet (1/T))$

and finally,

$G = 0.09$.

Substituting $G = 0.09$ in either (1) or (2) yields an inflection temperature of:

$T = 16.2$ °C.

Substituting the value of -0.21 (which is the log of 1/2 the maximum growth rate, $G_{1/2\ max}$) in equations (1) and (2) produces:

$T_1 = 9.2$ °C and
$T_2 = 22.7$ °C

which are the temperature cutoffs between the high growth and low growth seasons for this period.

In a similar manner for the 30 °C-0 °C temperature period, the calculated regression equations for the increasing and decreasing portions of the growth curve were:

5) $G = 0.49 - (9.95 \bullet (1/T))$ and
6) $G = -2.32 + (50.96\ (1/T))$

where G is the log growth rate, and T is the water temperature.

Solving simultaneously for G produces:

7) $50.96 \bullet G = 50.96 \bullet 0.49 - (50.96 \bullet 9.95 \bullet (1/T))$ and
8) $9.95 \bullet G = 9.95 \bullet (-2.32) + (9.95 \bullet 50.96 \bullet (1/T))$

therefore,

$G = 0.31$

for the second temperature period.

Again, substituting the quantity $G = 0.31$ into either (5) or (6) yields an inflection temperature of:

$T = 21.7$ °C.

Growth patterns of *Zostera marina*

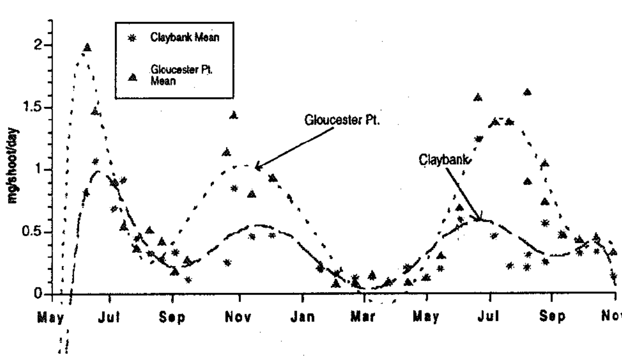

Figure V-95. Above ground shoot growth of *Zostera marina* for the Gloucester Point and Claybank sites for 1985-1986 data.

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Substituting the quantity -0.27 (which is the log of 1/2 the maximum growth rate) for G into (5) and (6) produces the seasonal temperature cutoffs for this second period of:

T_3 = 25.0 °C and
T_4 = 13.2 °C,
respectively.

In summary, the annual temperature cycle was divided into four distinct, biologically determined seasons (Figure V-96) that reflect the bimodal pattern of *Z. marina* growth characteristic of the polyhaline region of the Bay. These temperature-derived seasons are used to compare water quality parameters for the individual stations.

Water Quality Parameters

Habitat requirements for SAV in the polyhaline region of Chesapeake Bay were determined from combined growing season medians observed at those stations characterized by persistent stands of natural or transplanted vegetation in the York River. These seasons were either the spring or fall periods when significant differences in *Z. marina* growth were observed among the stations (described above). Water quality parameters selected for this model are those demonstrated to have the potential to influence plant survival: light attenuation coefficient, total suspended solids, chlorophyll *a*, dissolved inorganic nitrogen, and dissolved inorganic phosphorus.

Temperature

The subsurface (0.25 m) annual water temperature regime for the lower York River was characterized by rapid warming during the April-June period and cooling off during the October-December period as illustrated in Figure V-97.

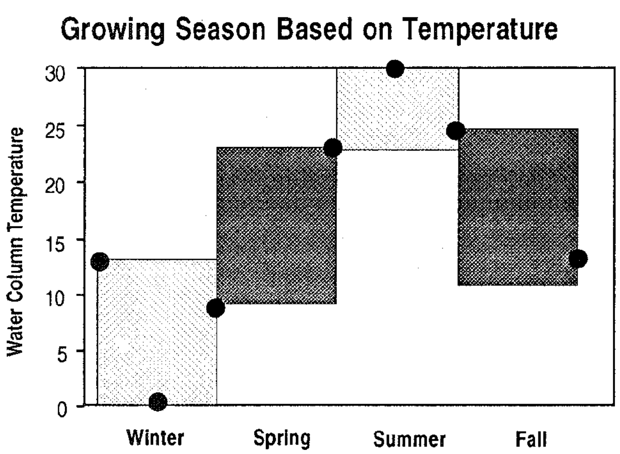


Figure V-96. *Zostera marina* based seasonal growth periods. The "winter" ranges from 13° - 0° - 9 °C, the "spring" from 9° - 23 °C, the "summer" from 23° - 30° - 25 °C and the "fall" from 25° - 13 °C.

Water temperature maxima approached 30 °C, minima was less than 5 °C with differences between stations not significant ($p<.05$).

Salinity

Salinity decreased with distance upriver (Figure V-98). Annual minimums were reported during the period of December - April. Although values to 6 ppt were occasionally recorded, levels at the most upstream station were generally greater than 10 (ppt). Maximums at this site in the August-October period regularly approached 20 ppt. Therefore, the entire reach can be characterized as mesohaline to polyhaline and generally suitable for only those two species of SAV tolerant of relatively high salinity levels–*Z. marina* and *R. maritima.*

Light Attenuation Coefficient

Light attenuation coefficient in the York River increases with distance upriver (Figure V-99), paralleling patterns observed for total suspended solids. Figure V-100 presents the least squares regression of light attenuation on total suspended solids. Although a large amount of variability results in a coefficient of determination (r^2) of only 0.56, the relationship suggests that particulates are the main factor affecting light attenuation in this region. Of this particulate load, the inorganic particles (e.g., suspended silts and clays) appear to be the principal component; whereas phytoplankton or phytoplankton-derived material in the water column probably play a smaller role in blocking sunlight from the SAV.

The percent of total light attenuation due to the chlorophyll *a* determined phytoplankton and phytoplankton derived components of the suspended load was estimated as:

$$((1-e^{-C \cdot Chl})/(1-e^{-Kd})) \cdot 100$$

where,

C is .016 $m^2 \cdot mg^{-1}$ Chl *a* (after Bannister, 1974);
Chl is mg Chl $a \cdot m^{-3}$; and,
Kd is total light attenuation $\cdot m^{-1}$.

The values were low at the Guinea Marsh and Claybank sites (Figure V-101) (less than 20% for the 1985-1987 period) but increased substantially from 1988-1989. This increase parallels the rise in chlorophyll *a* reported for the nearshore stations. Since few differences were observed among stations for seasonal means of chlorophyll *a* concentrations for the 1984-1987 period, phytoplankton most likely was not the sole factor limiting SAV growth, but was a significant, additional stress.

The highest seasonal levels of light attenuation observed in this study at vegetated sites were 2.0 m^{-1}. The combined growing season median light attenuation coefficient values were <1.5 m^{-1} at vegetated sites (see Figures V-115 and V-116).

Total Suspended Solids

Total suspended solids were markedly higher with distance upriver (Figure V-102). As illustrated in the Claybank site, concentrations were quite variable because the shallows were strongly influenced by resuspension due to wind. Seasonal means (plant-derived seasons) for total suspended solids were compared for the vegetated Gloucester Point station and the currently unvegetated Claybank station by two-way ANOVA (Figure V-103). Means were used because two-way ANOVA tests for differences among means. Levels were generally significantly greater ($p<0.05$) at the Claybank site each spring when compared to the downriver Gloucester Point station. Total suspended solid levels were generally highest during the spring period. The suspended load was composed principally of inorganic particles as the organic content was generally less than 30%. This percentage decreased with distance upriver, suggesting that the riverine input was enriched with inorganic silts and clays relative to the estuary.

The combined growing season median concentrations of total suspended solids observed in the downriver sites where SAV have maintained viable populations was approximately 15 mg/l at the Gloucester Point site. Since levels at the upriver Claybank site, where SAV currently will not grow, are significantly higher (particularly during the spring when differences in growth of transplants are most marked), <15 mg/l combined seasonal median concentration of total suspended solids was determined to be an important threshold for the plants (see Figure V-115).

Chlorophyll a

When compared seasonally, there were few significant differences in chlorophyll *a* concentrations between the Claybank and Gloucester Point stations ($p<0.05$) (Figure V-104). Marked increases in chlorophyll *a* levels were observed in both stations beginning in the fall of 1987 when levels rose from <10 μg/l to between 10-20 μg/l (Figure V-105).

Although chlorophyll *a* may be an imperfect measure of true phytoplankton biomass, it is a widely measured parameter and as yet, there is no evidence of significant phytoplankton populations such as found in Long Island embayments (Cosper *et al.* 1987; Dennison *et al.* 1989), which may bias its use as a measure of phytoplankton biomass in the Chesapeake Bay region. Highest seasonal levels observed in this study were 15 μg/l at the downriver vegetated sites. Combined growing season median concentrations of chlorophyll *a* at these same sites were <15 ug/l (see Figure V-115).

Dissolved Inorganic Nitrogen

Increases in dissolved inorganic nitrogen levels to 0.35 mg/l were observed annually in the lower York River nearshore areas from October-February (Figure V-106). With distance upriver, concentrations rose earlier and maintained higher levels longer. Differences among station seasonal means were apparent only during the fall and winter as demonstrated for the Gloucester Point and Claybank sites (Figure V-107). Dissolved inorganic nitrogen species consisted principally of ammonium and nitrite with lower levels of nitrate.

Highest seasonal levels of dissolved inorganic nitrogen at vegetated sites were observed to be approximately 0.28 mg^{-1} during the fall period. The combined growing season median concentrations were <0.15 mg/l (see Figure V-116). Since little difference in SAV growth was observed among sites during the winter, when dissolved inorganic nitrogen levels could be higher than these concentrations, the combined growing season median was chosen as the dissolved inorganic nitrogen habitat requirement. It is most likely that low water temperatures, as well as low light levels, are limiting SAV growth in this region during the winter. Both epiphytic algae and phytoplankton are also limited by these two factors, allowing dissolved inorganic nitrogen to reach high levels.

Dissolved Inorganic Phosphorus

Dissolved inorganic phosphorus levels demonstrated less annual variability than nitrogen, with the highest levels occurring in the late summer and fall (Figure V-108). Comparison of seasonal means between Gloucester Point and Claybank stations revealed significantly increasing levels with distance upriver during most seasons (Figure V-109). Highest seasonal levels were approximately 0.03 mg/l during the spring or fall at vegetated sites. The combined growing season median concentrations were <0.02 mg/l at vegetated sites and therefore was chosen to characterize the SAV habitat requirement for dissolved inorganic phosphorus (see Figure V-116).

Nitrogen:Phosphorus Ratios

Atomic ratios of dissolved inorganic nitrogen to dissolved inorganic phosphorus demonstrated seasonal variation which was largely a function of seasonal nitrogen input (Figure V-110). Generally the nitrogen:phosphorus ratios suggest that nitrogen should be limiting for phytoplankton growth during much of the year, except during the late fall and

York River Nearshore 1984-1989

Water Temperature

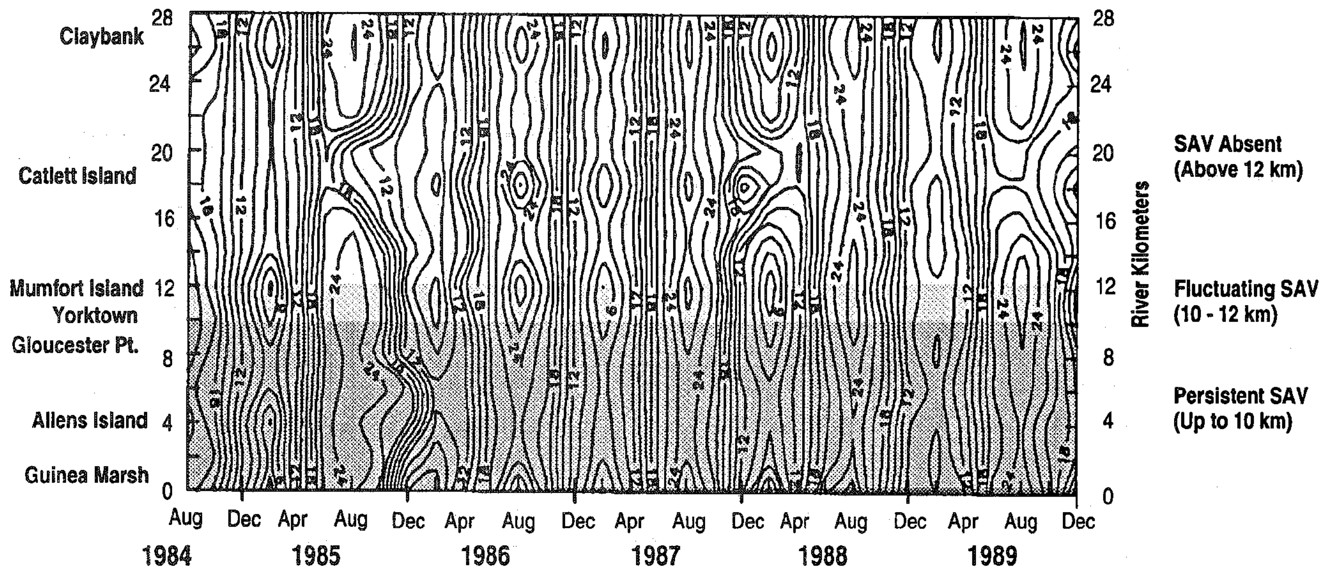


Figure V-97. Water temperature (°C) in the York River displayed by river kilometer over time.

York River Nearshore 1984-1989

Salinity

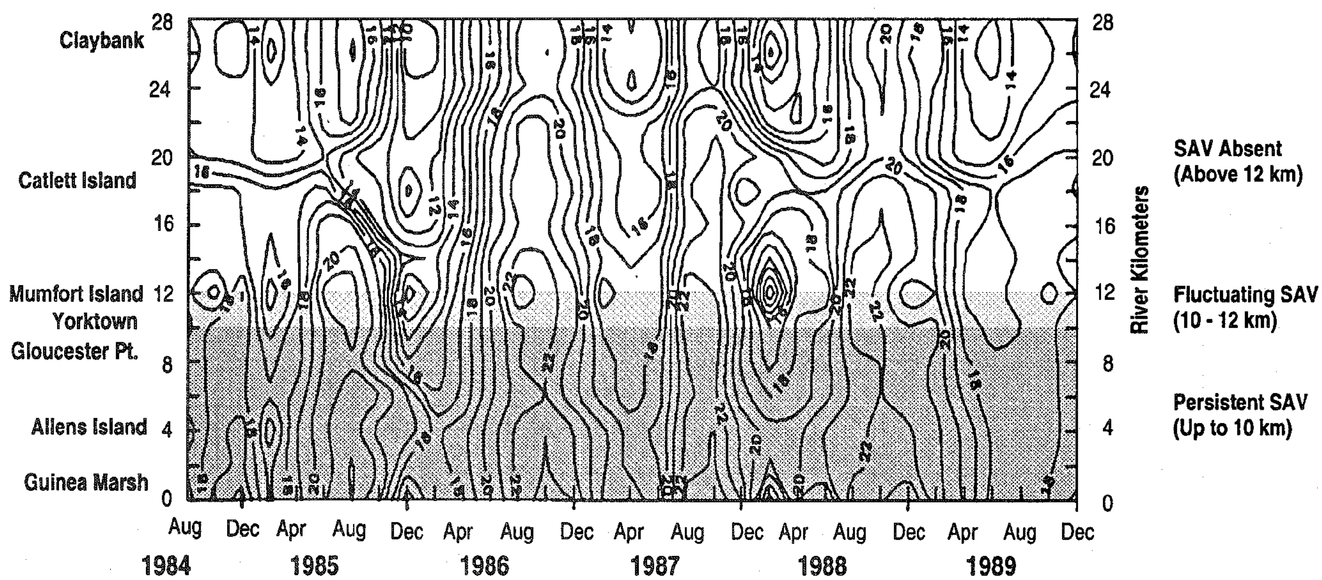


Figure V-98. Salinity (ppt) in the York River displayed by river kilometer over time.

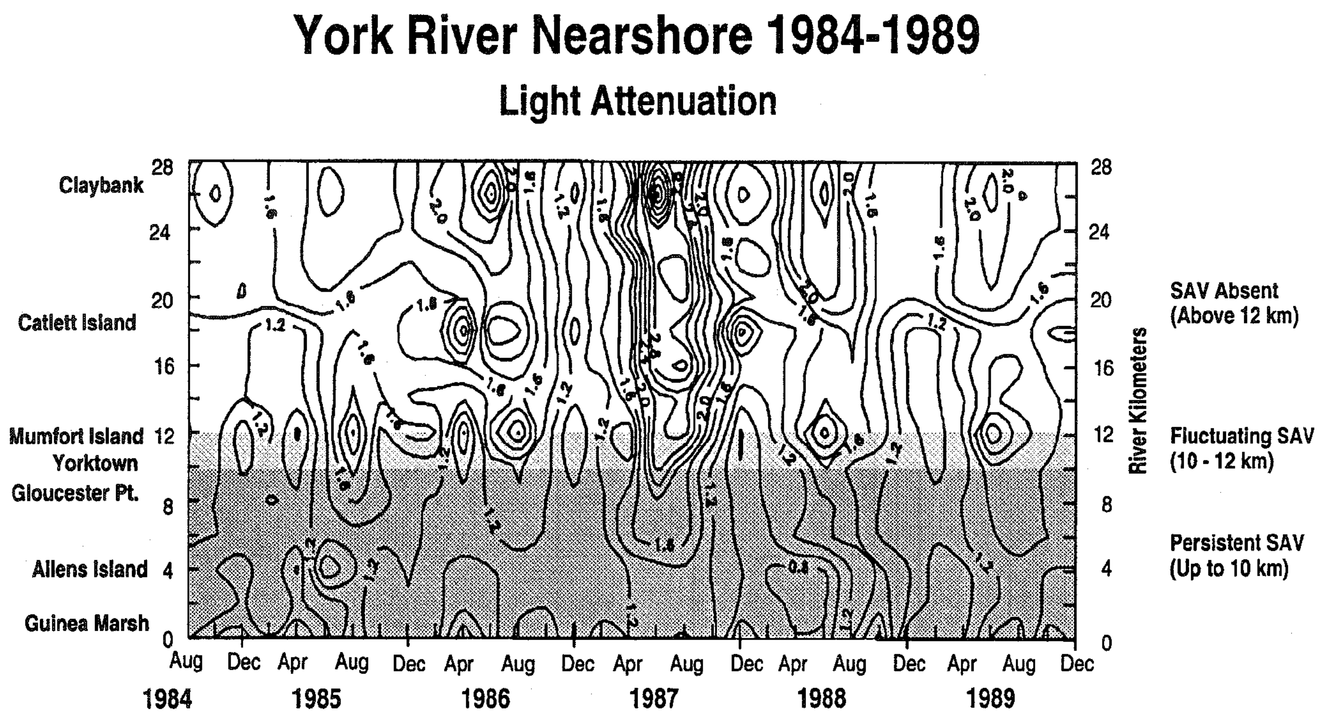


Figure V-99. Light attenuation (m^{-1}) in the York River displayed by river kilometer over time.

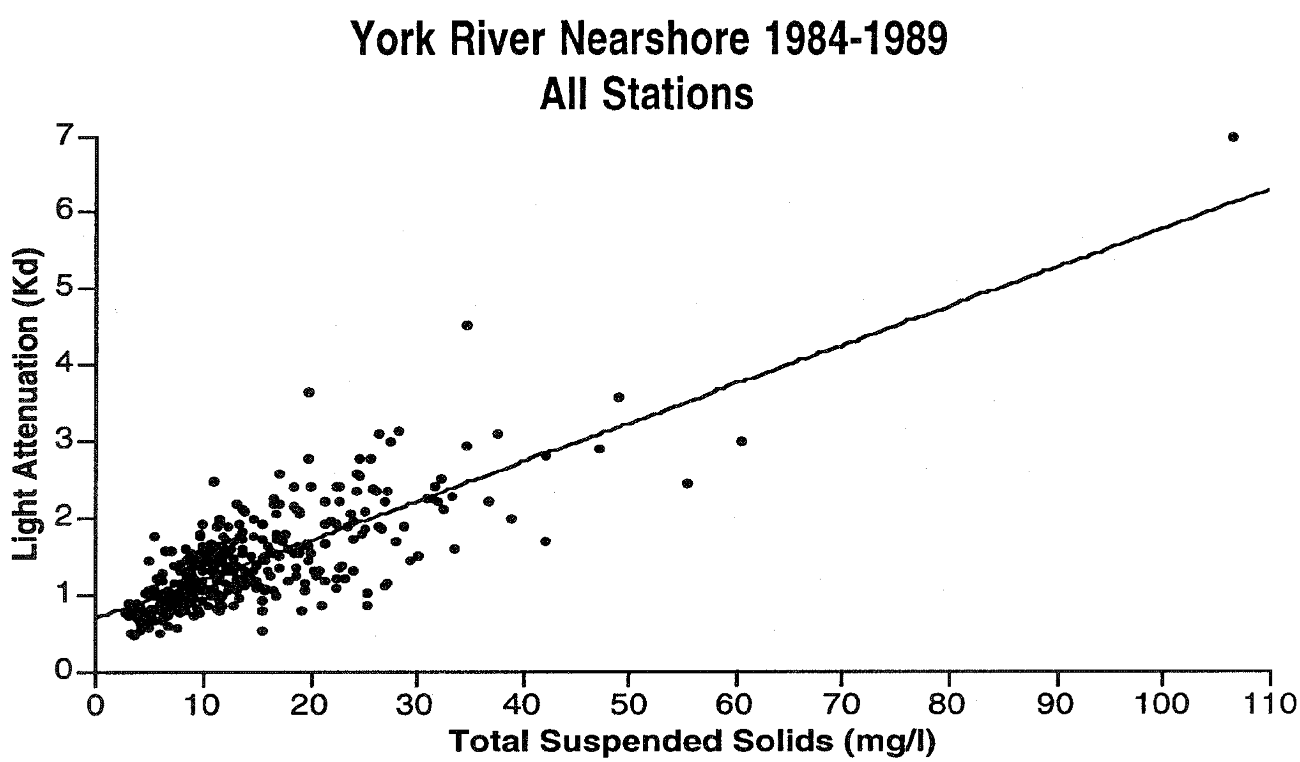
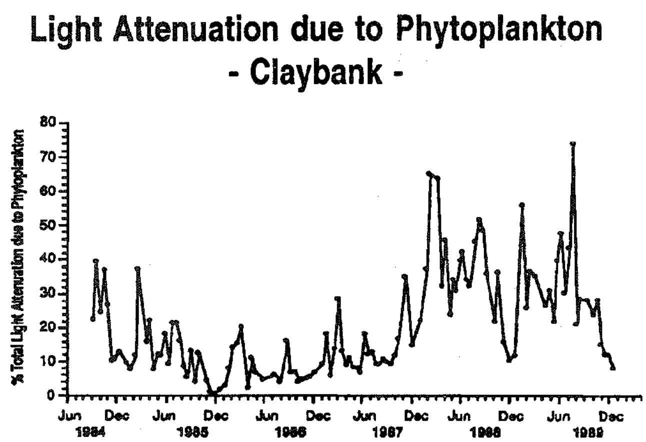


Figure V-100. Light attenuation as a function of total suspended solids for all York River stations, 1984-1989.



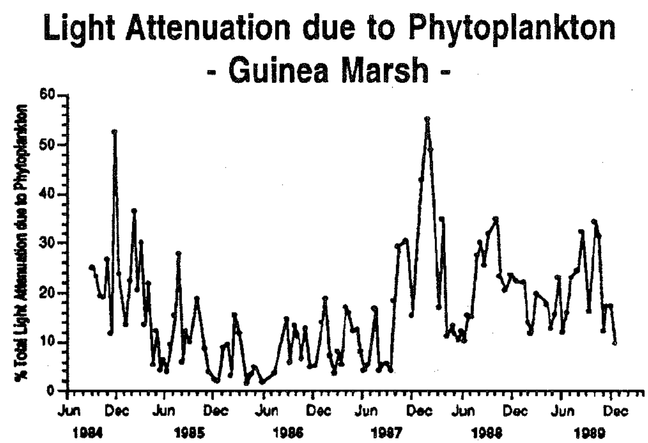


Figure V-101. Total light attenuation due to phytoplankton in the York River at Claybank and Guinea Marsh.

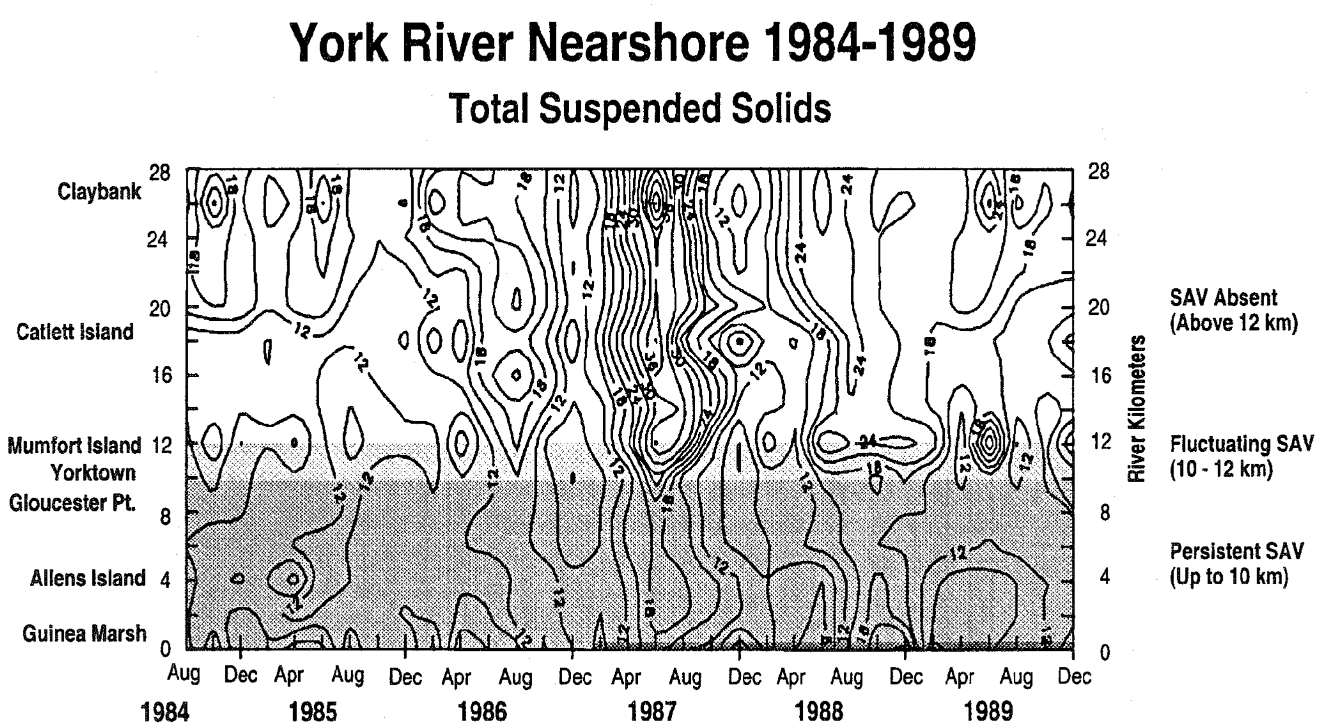


Figure V-102. Total suspended solids (mg/l) in the York River displayed by river kilometer over time.

winter when inorganic nitrogen levels increase. The effects of this availability on epiphytic production are as yet undetermined; however, the epiphytes should react in a similar manner to phytoplankton if other factors such as light are not limiting. Given these levels of dissolved inorganic nitrogen: dissolved inorganic phosphorus, it is possible that under current conditions dissolved inorganic phosphorus may not be limiting for phytoplankton and epiphytic growth in this region, particularly during the spring and fall SAV growth periods. If dissolved inorganic nitrogen inputs increase the availability of excess phosphate, this would lead to increased blooms of both epiphytic and planktonic algae.

In summary, environmental conditions in nearshore habitats of the lower York River region were characterized by elevated levels of total suspended solids and light attenuation during the spring growing season and elevated levels of dissolved inorganic nitrogen during the fall and winter in upstream unvegetated sites. Since these were the same periods when differences in transplant growth were observed, the hypothesis of a linkage between water quality and plant survival is supported. The mechanism of this linkage is still unclear. Phytoplankton levels, which may respond to increased availability of dissolved inorganic nutrients in the water column, were not markedly different between sites that demonstrated distinct differences in SAV survival. They were, however, a significant proportion of the suspended load and may increase SAV susceptibility to increased levels of suspended inorganic particles. Twilley *et al.* (1985) reported that phytoplankton contributed substantially to light attenuation in their high dosage fertilized ponds around the Choptank River. Using the same relationship of chlorophyll *a* concentration to equivalent light attenuation, for a light attenuation coefficient value of approximately 3.0 m^{-1} (found in their high nutrient ponds), 45% of the total water column light attenuation was due to phytoplankton. Values for lower York stations are generally below this level.

Epiphytes

Epiphytes may also have limited SAV production in the York River. Where the loadings were comparable to measured levels in other areas, microepiphytic mass was determined on a whole shoot basis for transplants at the Guinea Marsh, Gloucester Point, and Claybank sites in 1985 and 1986 (Sand-Jensen and Borum 1983, Bulthuis and Woelkering 1983, Borum *et al.* 1984). During the fall and winter, epiphyte levels were usually higher in the downriver reaches. These epiphyte levels may have had some impact on the slightly lower SAV growth observed downriver. During the late spring, there was an overall increase in epiphyte levels with distance upriver which may have influenced the differential patterns of SAV production and survival. Although Wetzel and Neckles (1986) suggested that epiphytic accumulation had little effect on SAV survival under average light levels, they predicted that under conditions of high light attenuation relatively small changes in epiphyte loadings would have dramatic effects on SAV survival.

In field experiments, a relationship between increased epiphyte loadings and nutrient levels was not apparent. This lack of relationship was likely due to the fact that in turbid estuaries, such as Chesapeake Bay, detritus and inorganic sediments entrapped by epiphytes may dominate light reduction at leaf surfaces (Kemp *et al.* 1983). Higher epiphyte levels during the spring at the upriver stations may reflect this entrapment, since suspended sediment levels are highest at this time of year. This lack of correlation between epiphytes and nutrients during the fall and winter suggests that due to the level of nutrient enrichment, other factors such as invertebrate epiphytes grazing activity or light availability may be limiting epiphytic accumulations.

Seasonal Total Suspended Solids - York River

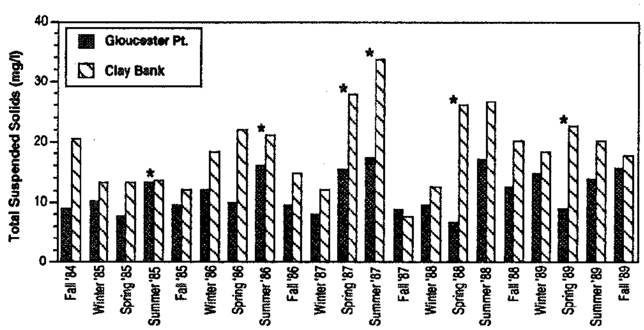


Figure V-103. Seasonal total suspended solids means in the York River at Gloucester Point and Claybank. Asterisks show significant differences ($p<0.05$).

Seasonal Chlorophyll *a* - York River

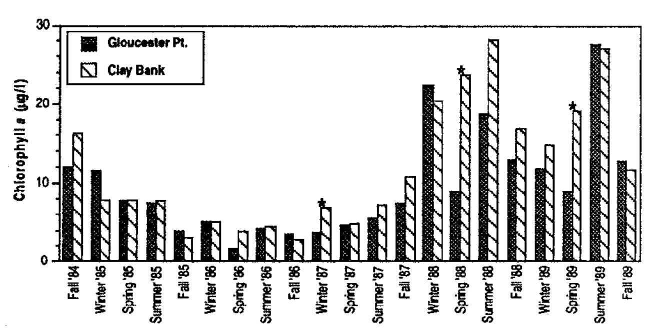


Figure V-104. Seasonal chlorophyll *a means* in the York River at Gloucester Point and Claybank. Asterisks show significant differences ($p<0.05$).

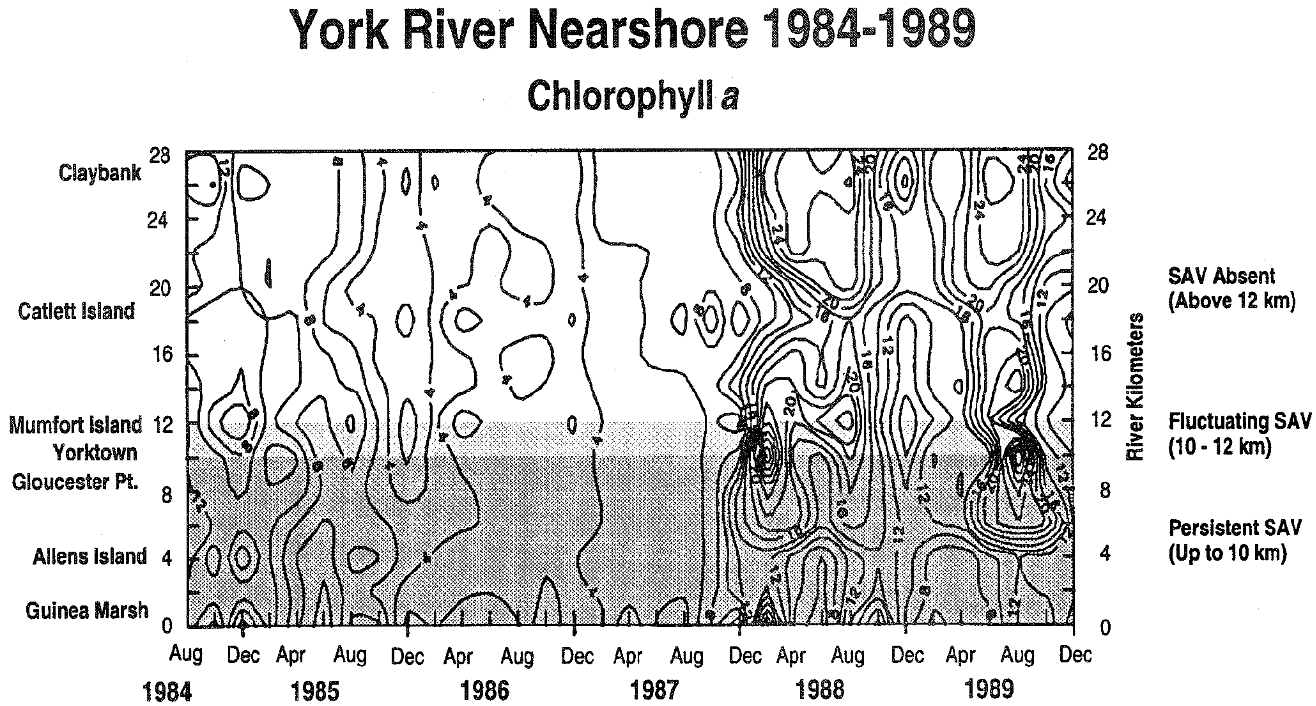


Figure V-105. Chlorophyll *a* (µg/l) in the York River displayed by river kilometer over time.

Microcosm Experiments

To test the single and interactive effects of nitrogen-phosphorus inputs and submarine photosynthetically active radiation on SAV growth and epiphytic fouling, a series of seasonal, four to six-week, microcosm experiments were conducted utilizing *Z. marina*. High, medium, and low light treatments were chosen to simulate turbidity levels that: 1) exceeded normal light availability in the York River (Kd = 0.84 m^{-1}); 2) were characteristic of where stable *Z. marina* beds were found (Kd = 1.23 m^{-1}); and, 3) were characteristic of areas where no SAV was present (Kd = 2.32 m^{-1}). The microcosms were flow-through systems fed with York River water from the Gloucester Point site. Nutrient treatments were ambient and enriched with 10 µg-at/l inorganic nitrogen and 1 µg-at/l inorganic phosphorus. Temperature and salinity varied with source water, and invertebrate grazers (*Diastoma varium*) were at densities of 5000 organisms per square meter.

Nutrients had no measurable effect on microepiphyte accumulation when expressed on a whole shoot gram-specific basis for the three seasonal experiments (Figure V-111). Plant response to nutrient enrichment likewise demonstrated no effect during the fall and spring. Gram-specific production, however, was reduced during the summer under enriched conditions (Figure V-112). These seasonal differences may have been related to increased macrophyte sensitivity created by higher water temperatures. As respiratory demands increase with temperature, the inhibitory effects of epiphytes on net plant growth should increase. Macrophytes demonstrated marked reductions in growth with decreasing levels of irradiance during all seasons (Figure V-113). Plant growth was reduced at both medium and low light treatments during the fall (when solar irradiance was lowest). During spring and summer, plant growth was reduced only at the lowest light levels. Grazers maintained consistent enrichment effects at all the light levels since there were no interactive effects of light and nutrients. Epiphytic growth also demonstrated marked light limitation, particularly at levels characteristic of upriver, denuded sites (Figure V-114).

In a companion study, Neckles (1990) found comparable results when testing the effects of nutrient enrichment and epiphytic grazers on *Z. marina* growth. She concluded that nutrient enrichment and epiphytic grazer activity interact to regulate epiphyte loadings on the macrophytes, with strong indirect effects on macrophyte production and survival. At levels of moderate nutrient enrichment (such as that observed in the Claybank region), grazer activity should negate the effects of enrichment on epiphyte loadings. Enrichment alone, therefore, should not limit survival, although it may depress annual macrophyte standing stocks. Enrichment may increase the plants' sensitivity to other potentially limiting factors, such as reduced levels of irradiance.

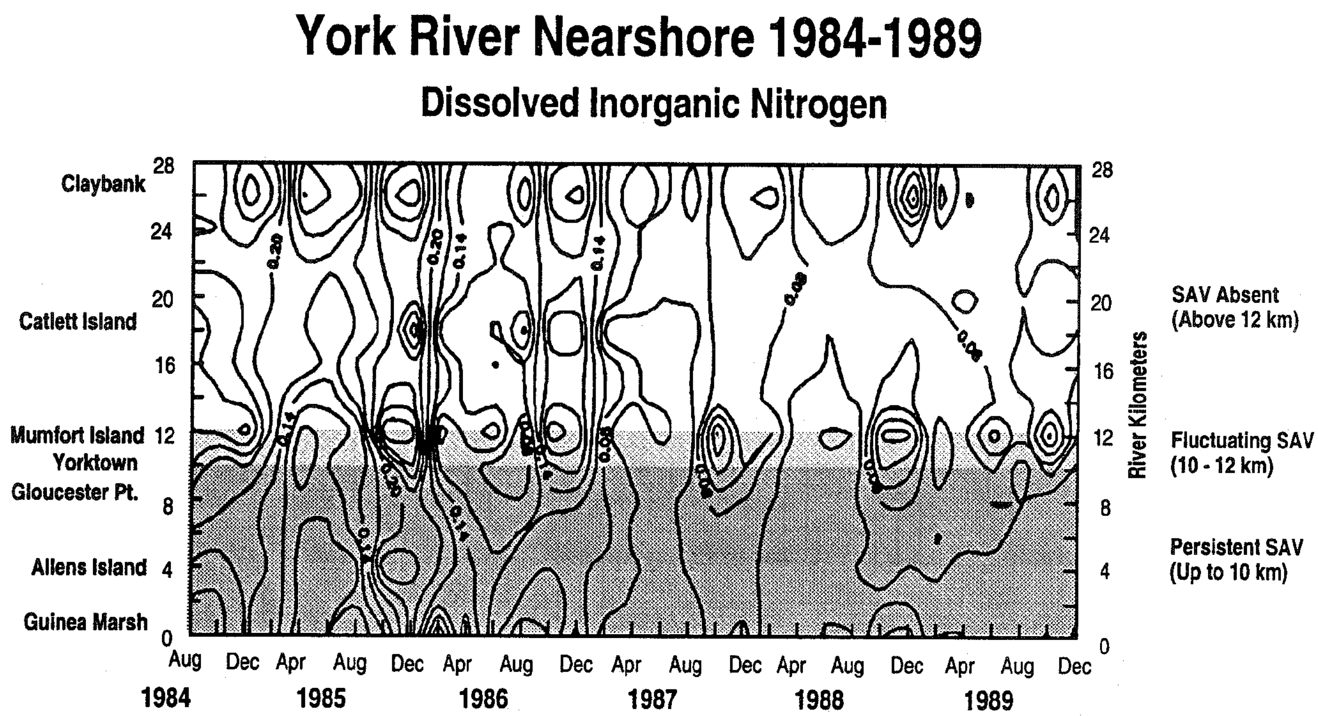


Figure V-106. Dissolved inorganic nitrogen (mg/l) in the York River displayed by river kilometer over time.

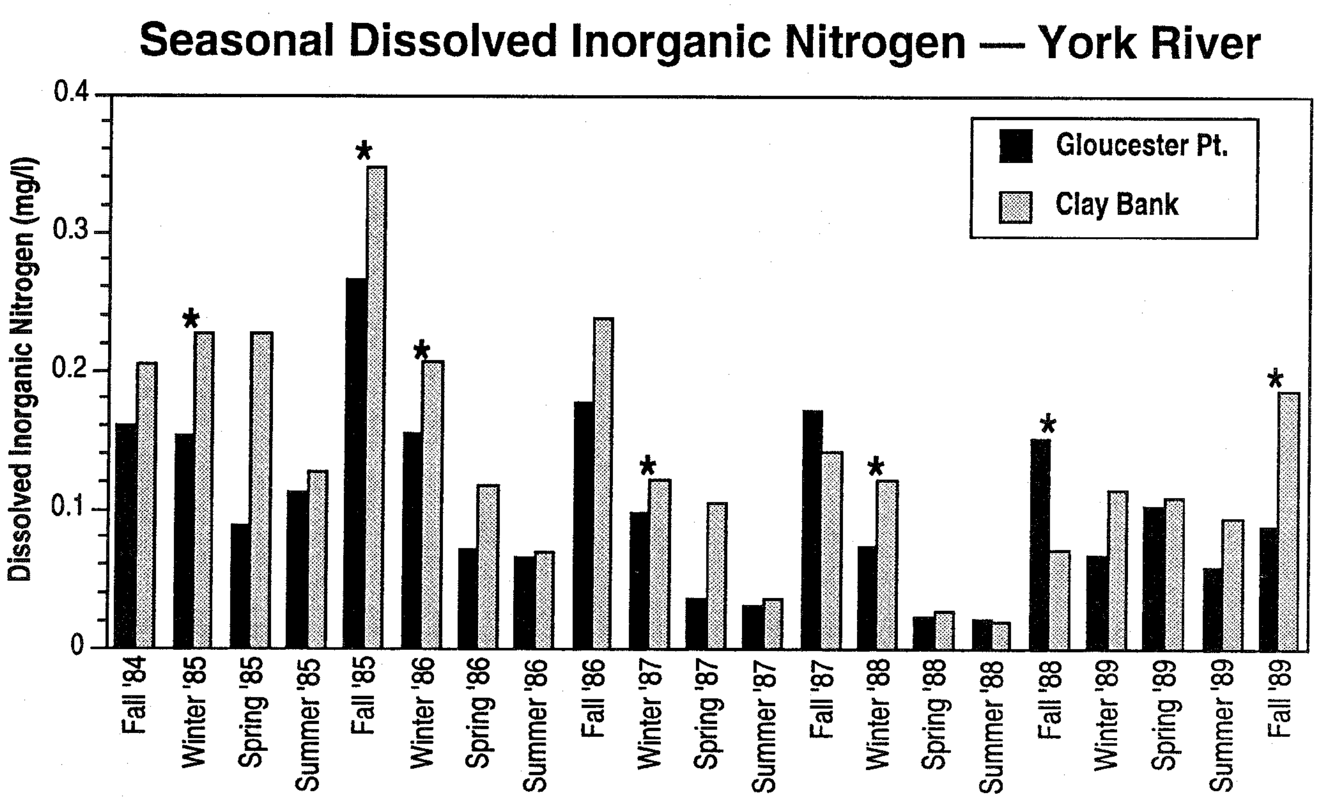


Figure V-107. Seasonal dissolved inorganic nitrogen in the York River at Gloucester Point and Claybank. Asterisks show significant differences (p<0.05).

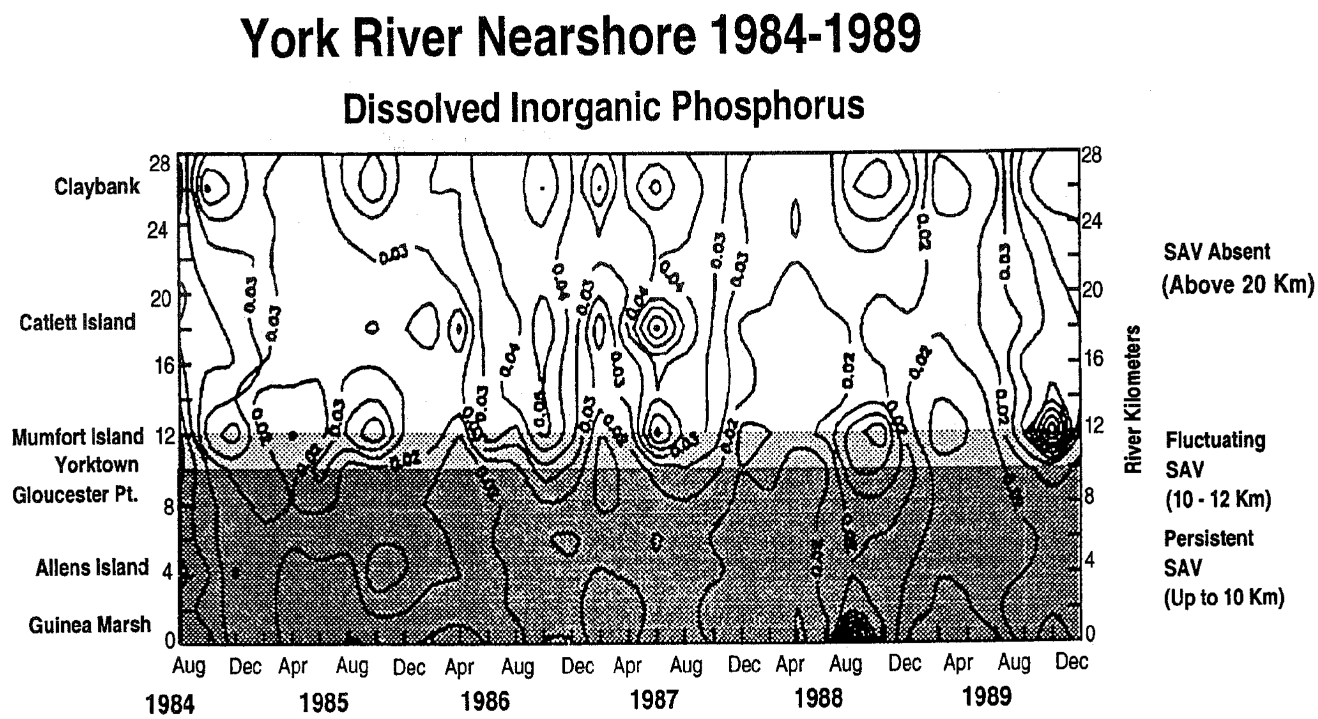


Figure V-108. Dissolved inorganic phosphorus in the York River displayed by river kilometer over time.

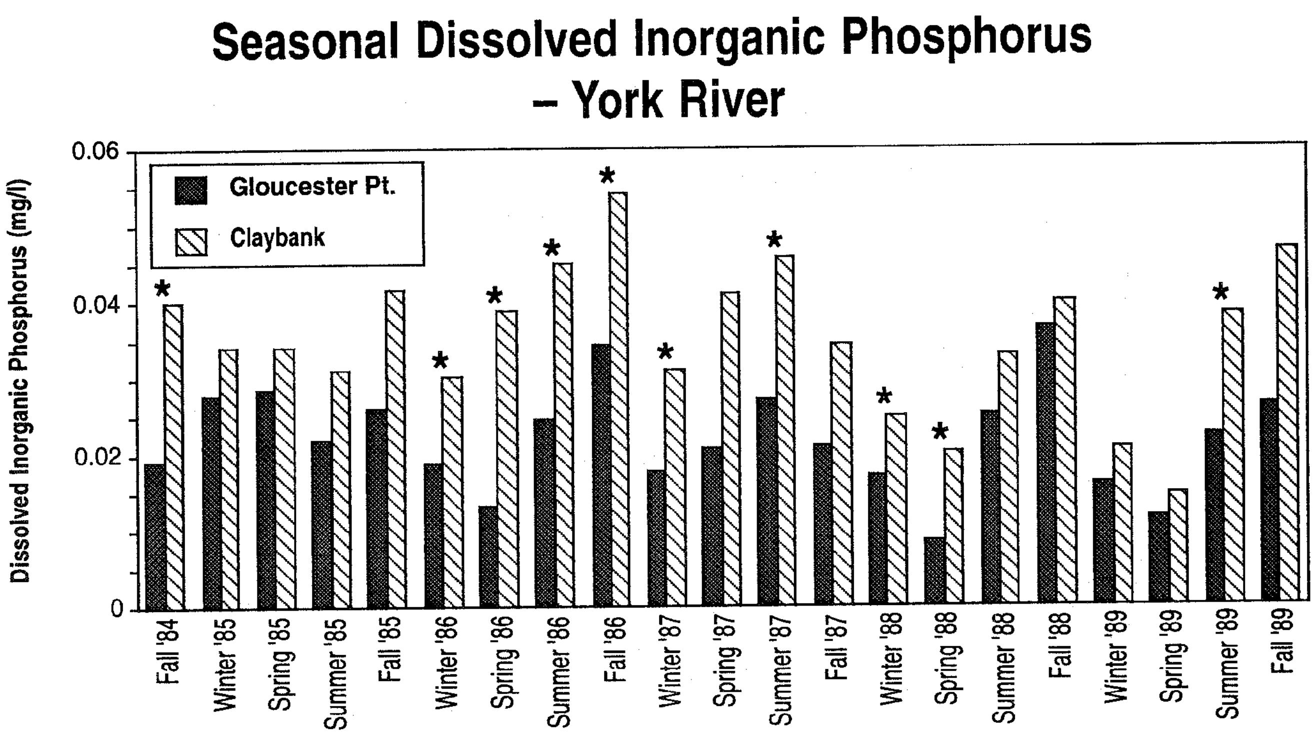


Figure V-109. Seasonal dissolved inorganic phosphorus means in the York River at Gloucester Point and Claybank. Asterisks show significant differences (p<0.05).

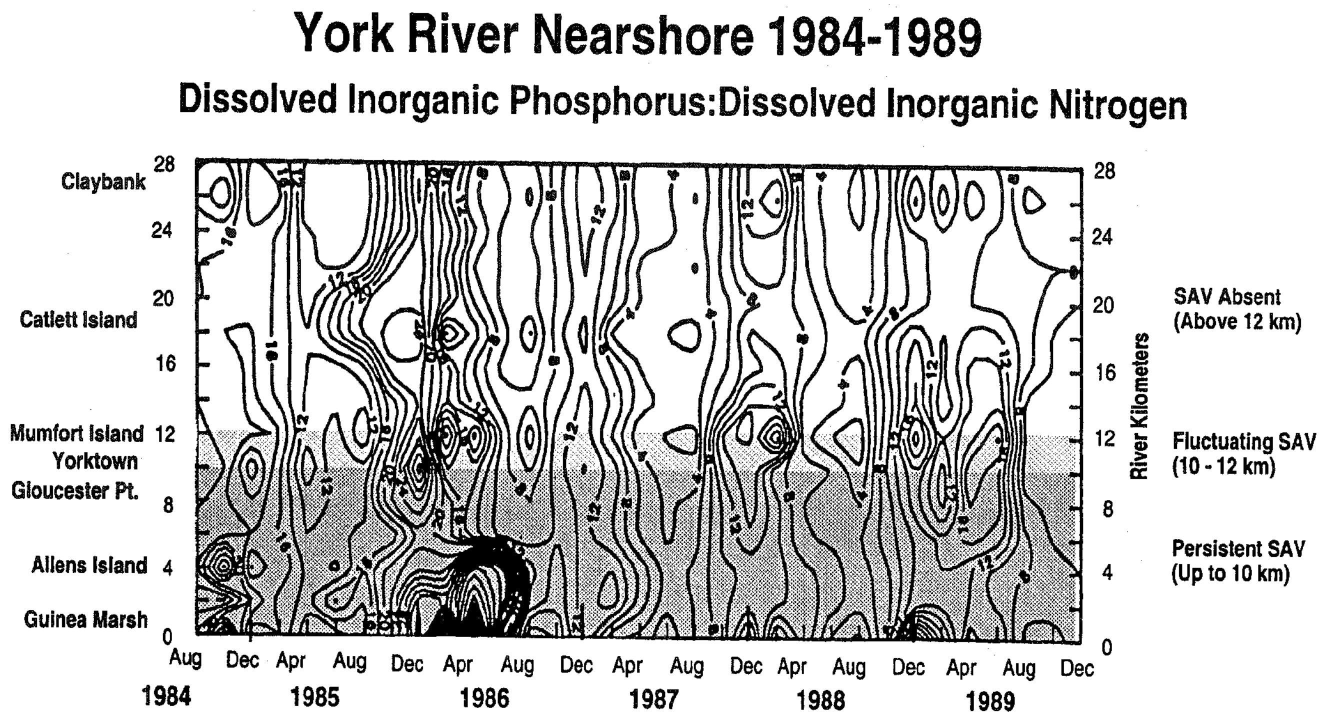


Figure V-110. Dissolved inorganic phosphorus/dissolved inorganic nitrogen ratios in the York River displayed by river kilometer over time.

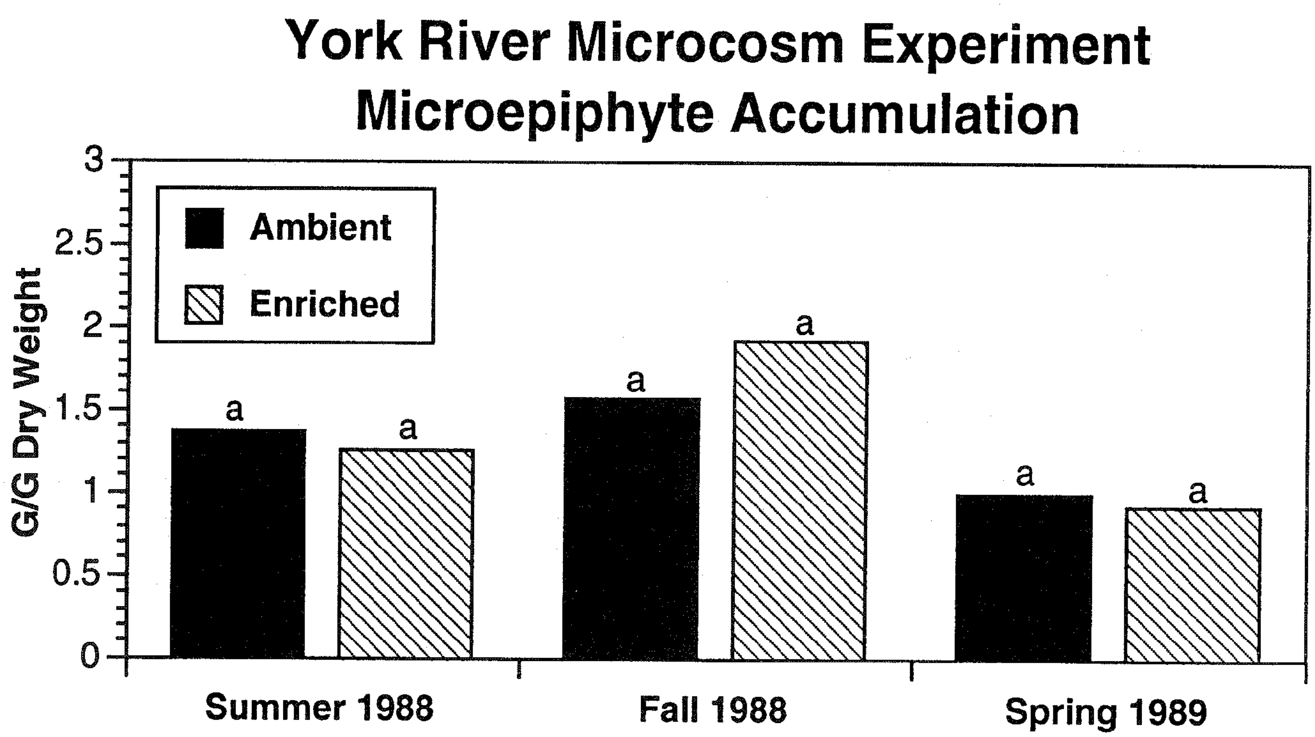


Figure V-111. Microcosm microepiphyte responses to enrichment treatments. Different lowercase letters denote significant differences between treatments at $p < 0.05$.

Table V-14. SAV Habitat Requirements for polyhaline habits in the York River applied as combined growing season medians.

Parameter	Habitat Requirement
Light Attenuation	$<1.5\ m^{-1}$
Total Suspended Solids	<15 mg/l
Chlorophyll *a*	<15 μg/l
Dissolved Inorganic Nitrogen	<0.15 mg/l
Dissolved Inorganic Phosphorus	<0.02 mg/l

Summary and Conclusions

These studies and experiments suggest that light availability is the principal mechanism controlling plant survival in polyhaline regions of the Bay. However, a variety of factors including seasonal solar irradiance, temperature, plant-sediment interactions, water column light attenuation, nutrient enrichment, and epiphytic grazer activity form a complex web of conditions that constrain productivity and ultimately survival. Attempts to characterize suitable habitat should not focus on a single limiting factor but on the range of variables influencing net growth.

The habitat requirements of SAV in the polyhaline regions of the Bay are presented in Table V-14. Three-dimensional comparisons of total suspended solids, chlorophyll *a*, and light attenuation coefficient (Figure V-115) and dissolved inorganic nitrogen, dissolved inorganic phosphorus, and light attenuation coefficient (Figure V-116) illustrate both the basis for the polyhaline SAV habitat requirements and the interrelationships between these parameters. It is predicted, therefore, that *Z. marina* dominated beds in these areas will survive at sites where levels of the water quality variables are at or below the values in Table V-14. Given the complex interaction of potentially important factors, goals to improve water quality should focus on all factors rather than any single factor.

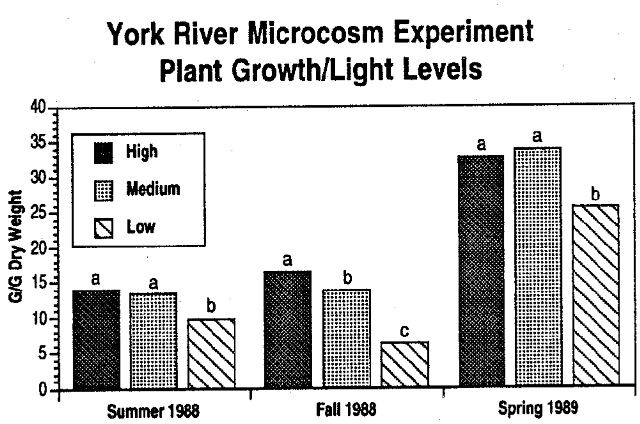


Figure V-113. Microcosm macrophyte responses to light reduction treatments. Different lowercase letters denote significant differences between treatments at $p < 0.05$.

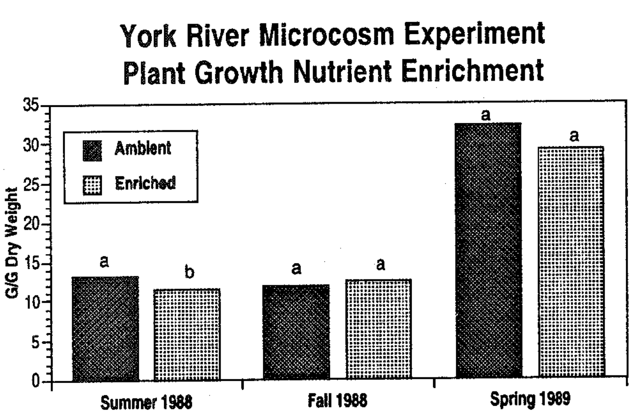


Figure V-112. Microcosm macrophyte responses to enrichment treatments. Different lowercase letters denote significant differences between treatments at $p < 0.05$.

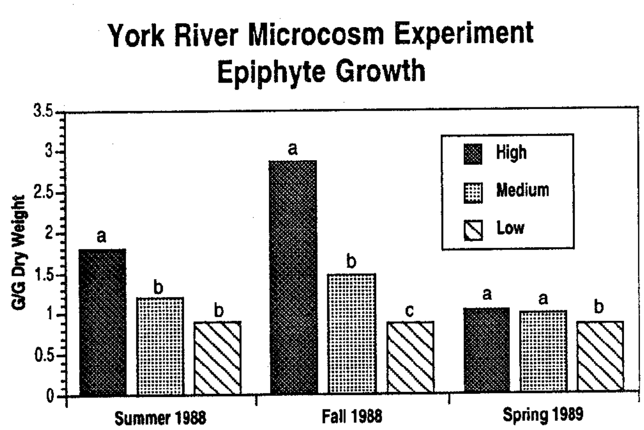


Figure V-114. Microcosm microepiphyte responses to light reduction treatments. Different lowercase letters denote significant differences between treatments at pz<0.05.

Total Suspended Solids, Chlorophyll *a*, and Light Attenuation: York River

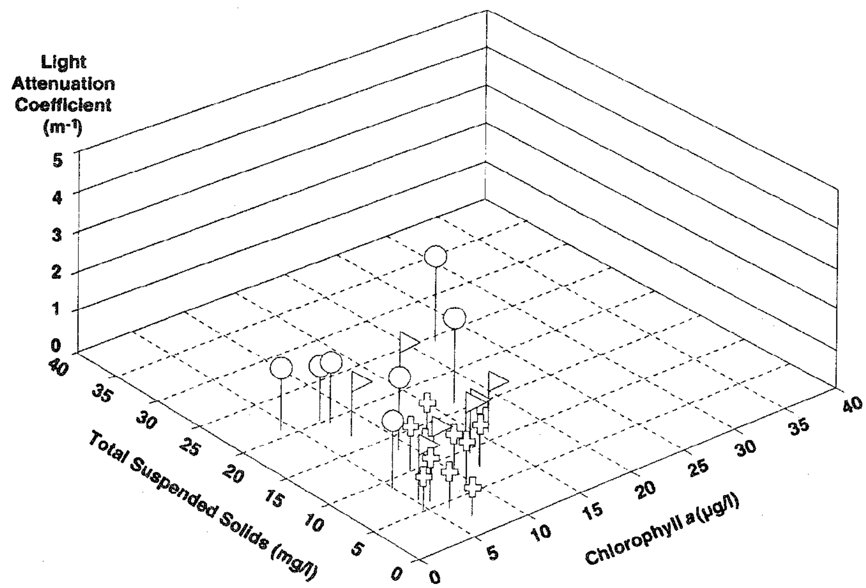


Figure V-115. Three-dimensional comparisons of combined March - May and September - November median light attenuation coefficient, total suspended solids, and chlorophyll *a* concentrations at the York River stations from 1986-1989. Stations and years are plotted separately with SAV status indicated. Plus = persistent SAV; flag = fluctuating SAV; circle = absent SAV.

Dissolved Inorganic Nitrogen, Dissolved Inorganic Phosphorus, and Light Attenuation: York River

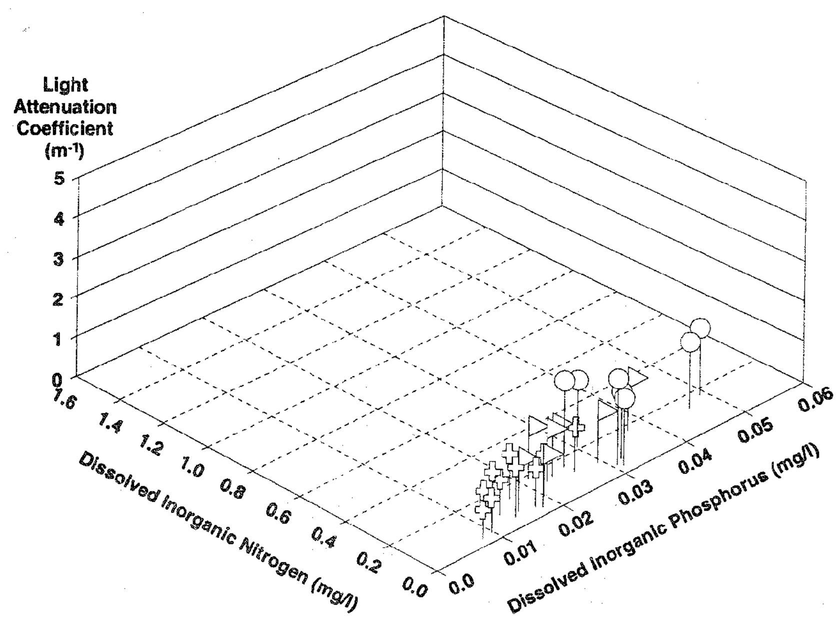


Figure V-116. Three-dimensional comparisons of combined March - May and September - November median light attenuation coefficient, dissolved inorganic nitrogen, and dissolved inorganic phosphorus concentrations at the York River stations from 1986-1989. Stations and years are plotted separately with SAV status indicated. Plus = persistent SAV; flag = fluctuating SAV; circle = absent SAV.

Chapter VI
Chesapeake Bay SAV Restoration Targets

The Submerged Aquatic Vegetation (SAV) Policy for the Chesapeake Bay and Tidal Tributaries (Chesapeake Executive Council 1989) established the goal to achieve a net gain in SAV distribution and abundance by "setting of regional SAV restoration goals considering historical distribution records and estimates of potential habitat." The baywide and regional SAV distribution, density, and species distribution/diversity targets, presented here, are critical in assessing the success of efforts to restore SAV in Chesapeake Bay.

Chesapeake Bay SAV Distribution Restoration Targets

Distribution Target Development Approach

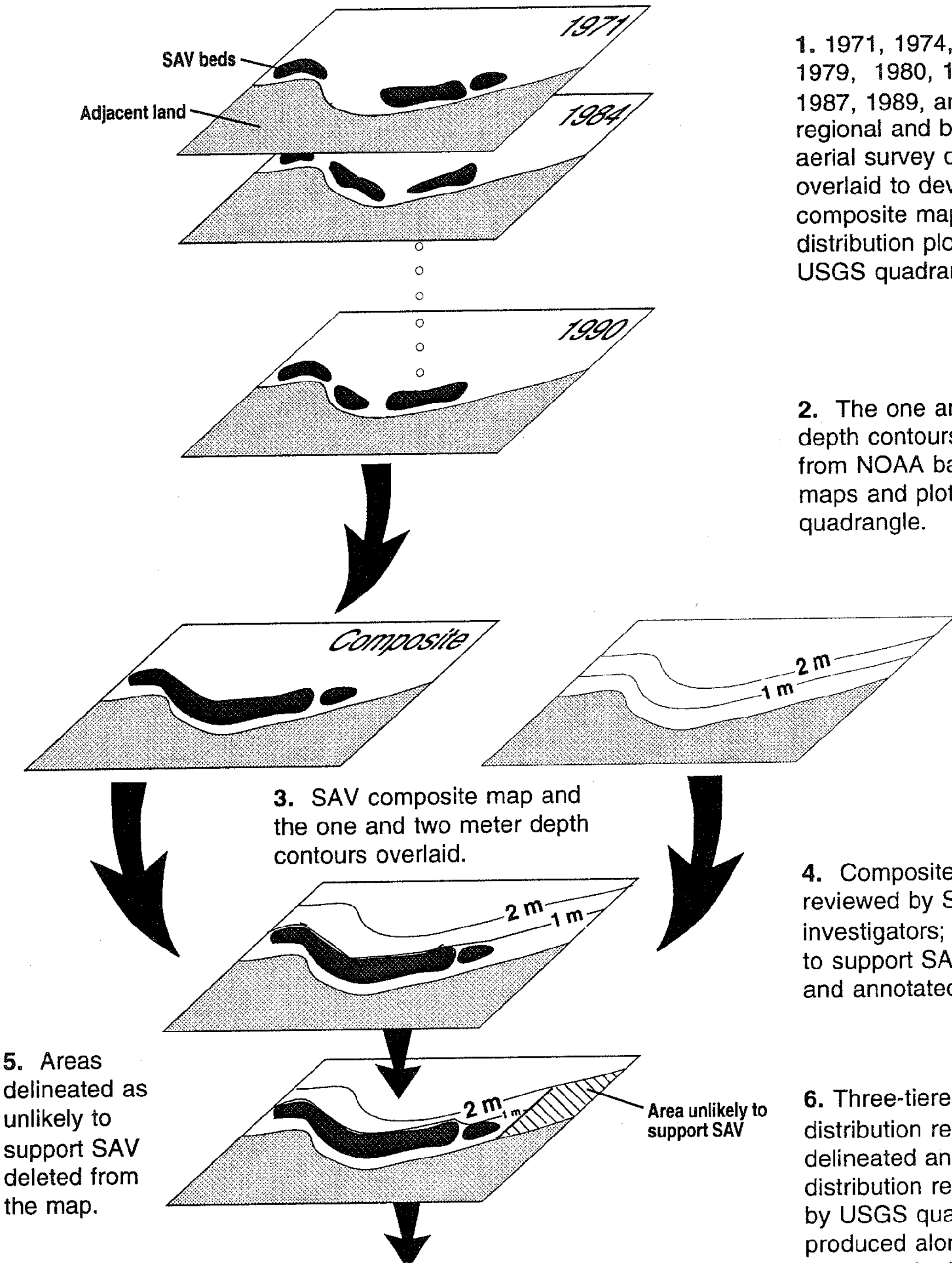
Chesapeake Bay SAV distribution restoration targets were developed by: mapping potential SAV habitat on U.S. Geological Survey (USGS) quadrangles; removing shallow water habitat areas where SAV were not expected to revegetate; and, comparing these areas with historical survey data and the most current distribution data (Figure VI-1). Composite SAV maps were plotted by USGS quadrangles from all available computerized digital SAV bed data from Chesapeake Bay aerial surveys (Orth unpublished 1971, 1974, 1980, and 1981 data; Orth *et al.* 1979, 1985, 1986, 1987, 1989, 1991; Orth and Nowak 1990; Anderson and Macomber 1980; Maryland Department of Natural Resources unpublished 1979 data). The 1 and 2 m depth contours at mean low water (MLW) were digitized from National Oceanic Atmospheric Administration (NOAA) bathymetry maps. Because the NOAA bathymetry maps are relatively inaccurate in small tidal creeks and rivers where depth contours were generally not present, an overestimate of an area within a certain depth contour can occur. These maps were overlaid at the 1:24,000 scale to produce composite maps of known and documented SAV distribution over time since the early 1970s, with the outline of potential SAV habitat initially defined by the 1 and 2 m depth contours. All digital data (stored on the Chesapeake Bay Program's ARC/INFO Geographic Information System) was digitized and documented following the quality assurance/quality control guidelines of Orth and Nowak (1990).

Potential habitat was initially defined as all shoal areas of Chesapeake Bay and tributaries less than 2 m. Although historical SAV in Chesapeake Bay probably grew to 3 m or more, the 2 m depth contour was chosen because it was the best compromise of the anticipated maximum depth penetration of most SAV species when both the 1 and 2 m habitat requirements for one and two meter restoration are achieved baywide. For several SAV species (notably *Myriophyllum spicatum* and *Hydrilla verticillata*) maximum depth penetration might be greater than 2 m, but it was felt that this would be an exception. The 1 m depth contour was selected because this is the limit of SAV depth penetration given achievement of the SAV habitat requirements for 1 m restoration.

Areas that were highly unlikely to support SAV were annotated on the composite maps by the principal investigators (Table VI-1). Criteria for excluding certain areas from the maps was based primarily on the principal investigators' application of information from early historical surveys, documented personal observations, and anecdotal information on the absence of SAV from a particular area since the last century. In addition, a detailed examination of data from the last two decades of SAV monitoring using aerial photography, ground survey documentation from the last 20 years, and historical photography was also included. Specific criteria using substrate and exposure were not used because of the complexities in SAV growth patterns in the Bay and tributaries that make the use of such criteria exceedingly difficult.

There was limited information that could be used to delineate and designate shallow water areas (less than 2 m MLW) as highly unlikely to support future SAV growth. The composite SAV maps included distribution data only covering the time period after significant SAV declines started in the 1960s and early 1970s. There was no baywide mapping of SAV until 1978, with a 5-year break before the next baywide survey in 1984. Historical aerial photography for shallow water areas was not available for many years and not on a baywide basis for any single year. The utility of the available historical photography was questionable at best since the photographs were not collected under

Process For Setting Chesapeake Bay SAV Distribution Restoration Targets



1. 1971, 1974, 1978, 1979, 1980, 1981, 1984-1987, 1989, and 1990 regional and baywide SAV aerial survey digital data overlaid to develop composite maps of SAV distribution plotted by USGS quadrangle.

2. The one and two meter depth contours digitized from NOAA bathymetry maps and plotted by USGS quadrangle.

3. SAV composite map and the one and two meter depth contours overlaid.

4. Composite map reviewed by SAV principal investigators; areas unlikely to support SAV delineated and annotated.

5. Areas delineated as unlikely to support SAV deleted from the map.

6. Three-tiered SAV distribution restoration targets delineated and maps of SAV distribution restoration targets by USGS quadrangle produced along with tables of acreages by USGS quadrangle, Chesapeake Bay SAV Aerial Survey Segment, and Chesapeake Bay Program segment.

Chesapeake Bay SAV Distribution Restoration Targets

Figure VI-1. Process for setting Chesapeake Bay SAV distribution restoration targets.

Table VI-1. Chesapeake Bay principal investigators responsible for reviewing the SAV composite maps to delineate the SAV distribution restoration targets.

Principal Investigator	Affiliation	Shoreline regions of the Chesapeake Bay reviewed
Robert Orth	Virginia Institute of Marine Science	Virginia western shore from Cape Charles to Point Lookout (including the James, Rappahannock, and York rivers); upper Maryland western shore from North Beach to Spesutie Island; upper Maryland Eastern Shore from Betterton south to Eastern Neck Island; lower Maryland and the entire Virginia Eastern Shore from Taylors Island to Cape Henry.
Lorie Staver	University of Maryland-Horn Point Environmental Laboratory	Maryland western shore from Point Lookout (at the mouth of the Potomac River) north to North Beach (including the Patuxent River); Maryland Eastern Shore from Taylors Island to Eastern Neck Island (including the Choptank River, Eastern Bay, and Chester River).
Stan Kollar	Harford Community College	Spesutie Island north to the Susquehanna Flats and down to Betterton at the mouth of the Sassafras River (including the Northeast and Elk rivers).
Virginia Carter	U.S. Geological Survey-Reston	Potomac River and its tributaries.

conditions required for photo-interpretation and mapping of SAV.

All available information was utilized during the process of defining the distribution restoration targets. Habitat areas exposed to high wave energy and which have undergone physical modifications to the point they could not support SAV growth were excluded based on a review of the information. The absence of documentation on the historical presence of SAV in a certain region of a tributary, embayment, or the mainstem was not used as a reason to delineate and exclude the shallow water habitats in these regions as unlikely to support future SAV growth. This type of information was used in establishing the tiered approach to target setting. For example, some areas that have not supported SAV in the recent past (such as the tidal fresh and oligohaline areas of the James, York, and Rappahannock) were included in the distribution restoration targets. This distinction was based on the following assumption: since the upper Potomac River near Washington, DC, supported dense stands of SAV in the early 1900s (Cumming *et al.* 1916), there should be no reason to assume that SAV was not present in similar areas in the tidal fresh and oligohaline reaches of other river systems in Chesapeake Bay. The anecdotal evidence from disparate regions of the Bay as well as aerial photographic evidence for some areas in the 1930s indicates the major areas where SAV grew in the early part of the 20th century. In addition, many small tidal creeks in tidal fresh and oligohaline areas throughout the Bay today contain small pockets of a variety of SAV species. It is assumed that these are the last remnants of what were once large expansive stands in earlier periods in the upper sections of these tributaries. The seed and pollen record (Brush and Hilgartner 1989) support this line of evidence that SAV was once significantly more abundant than it is today.

The areas annotated as highly unlikely to support SAV were digitized and deleted from the ARC/INFO files of potential SAV habitat delineated by the 2 m depth contour. A second level of habitat restriction was considered in those areas where SAV was presently found or had the potential to grow in the 2 m contour. This habitat restriction was considered in areas where wave exposure is highly likely to prevent SAV from growing down 2 m in depth but would be dampened enough to allow SAV to grow closer inshore (less than 1 m). Assessment of areas that would fall into this category was based on the same criteria used to generate the composite maps for the 2 m restricted areas.

SAV Distribution Restoration Targets

To provide stepwise measures of progress, a tiered set of SAV distribution restoration targets have been established

Table VI-2. Chesapeake Bay Program segment descriptions.

Segment	Description	Segment	Description
CB1	Northern Chesapeake Bay	TF3	Upper Rappahannock River
CB2	Upper Chesapeake Bay	RET3	Middle Rappahannock River
CB3	Upper Central Chesapeake Bay	LE3	Lower Rappahannock River
CB4	Middle Central Chesapeake Bay		
CB5	Lower Chesapeake Bay	TF4	Upper York River
CB6	Western Lower Chesapeake Bay	RET4	Middle York River
CB7	Eastern Lower Chesapeake Bay	LE4	Lower York River
CB8	Mouth of the Chesapeake Bay	WE4	Mobjack Bay
WT1	Bush River	TF5	Upper James River
WT2	Gunpowder River	RET5	Middle James River
WT3	Middle River	LE5	Lower James River
WT4	Back River		
WT5	Patapsco River	ET1	Northeast River
WT6	Magothy River	ET2	Elk/Bohemia Rivers
WT7	Severn River	ET3	Sassafras River
WT8	South/Rhode/West Rivers	ET4	Chester River
		ET5	Choptank River
TF1	Upper Patuxent River	ET6	Nanticoke River
RET1	Middle Patuxent River	ET7	Wicomico River
LE1	Lower Patuxent River	ET8	Manokin River
		ET9	Big Annemessex River
TF2	Upper Potomac River	ET10	Pocomoke River
RET2	Middle Potomac River		
LE2	Lower Potomac River	EE1	Eastern Bay
		EE2	Lower Choptank River
		EE3	Tangier Sound

for Chesapeake Bay. Each target represents expansions in SAV distribution that are anticipated in response to improvements in water quality. These water quality improvements will be measured as achievement of the SAV habitat requirements for one and two meter restoration. The SAV distribution restoration targets are presented by Chesapeake Bay Program Segment (Tables VI-2 and VI-3 and Figure VI-2), Chesapeake Bay SAV Aerial Survey Segment (Appendix D), and USGS quadrangle (Appendix D). Baywide maps of the Tier I and III SAV distribution restoration targets are presented in Figures VI-3 and VI-4.

Tier I Target: ***Restoration of SAV to areas currently or previously inhabited by SAV as mapped through regional and baywide aerial surveys from 1971 through 1990.***

Achievement of this SAV distribution restoration target depends on achievement of the SAV habitat requirements for one meter restoration (Table IV-1) in areas delineated as current or previous SAV habitat based on all aerial surveys conducted from 1971 through 1990, and on the presence of sufficient propagules and other environmental factors that limit growth (e.g., salinity, temperature, sediment substrate, herbicides) remaining within the tolerance limits of the SAV species.

Tier II Target: ***Restoration of SAV to all shallow water areas delineated as existing or potential SAV habitat down to the one meter depth contour.***

Achievement of this SAV distribution target also depends on achievement of the SAV habitat requirements for one meter restoration (Table IV-1) and aims for SAV growth down to one meter in depth. Tier II includes all areas in Tier I as well as all areas delineated within the one meter depth contour in the Chesapeake Bay and its tributaries. Tier II excludes a number of areas that are considered highly unlikely to support SAV. These areas occur in regions where the physical exposure to intense wave and current energy would prevent the establishment of any

Chesapeake Bay Program Segments

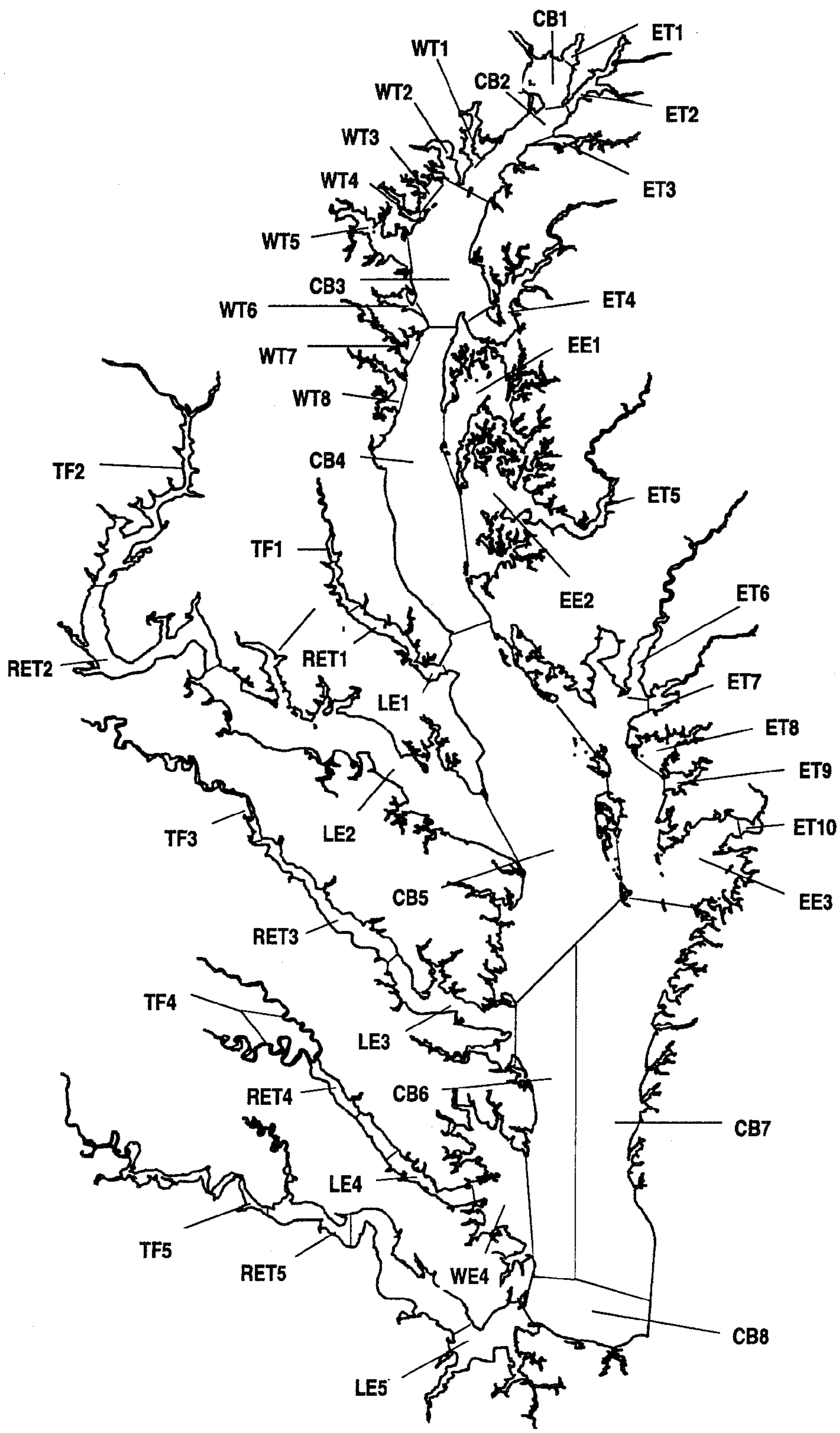
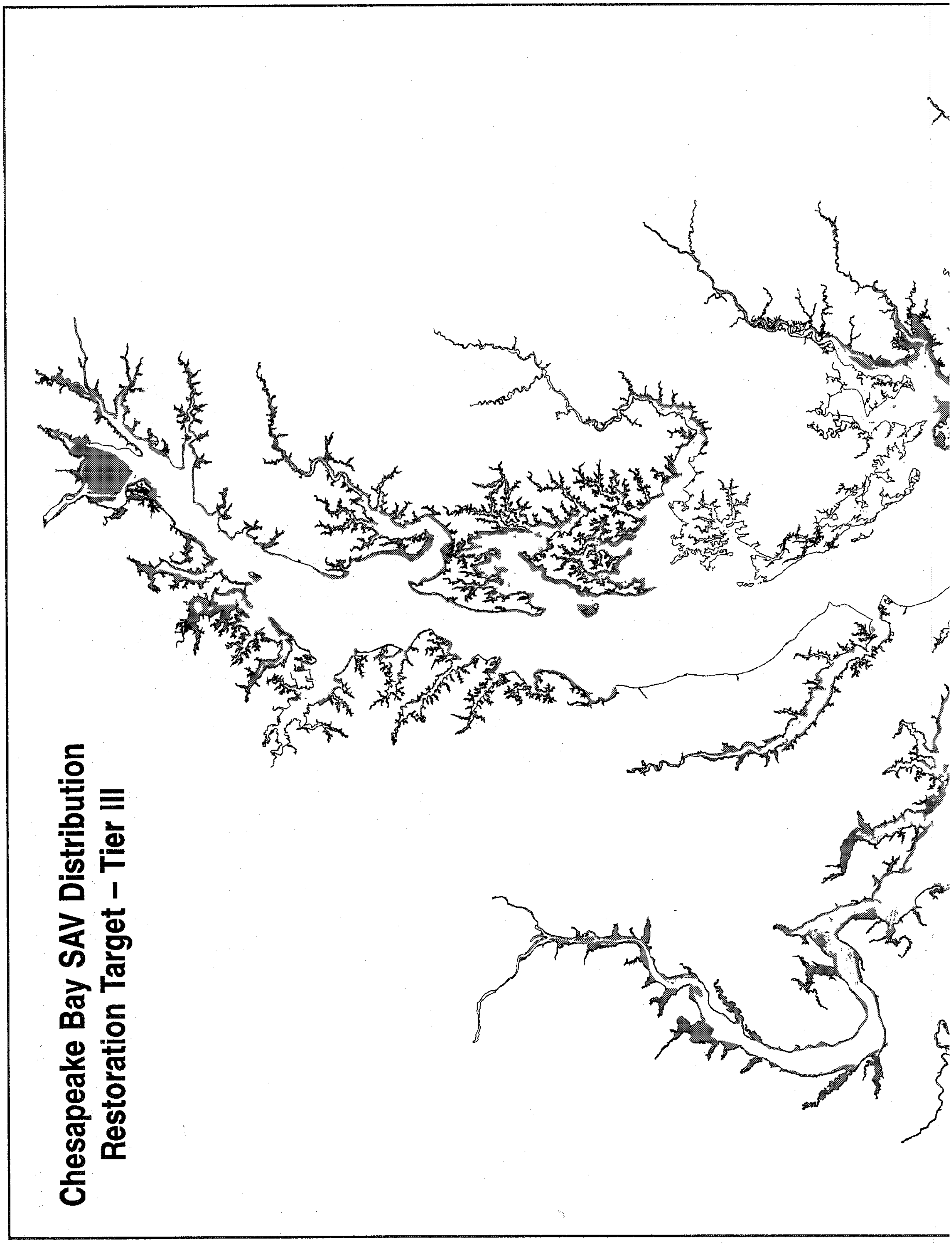


Figure VI-2. Chesapeake Bay Program segmentation scheme used to report the SAV distribution restoration targets.

Table VI-3. Chesapeake Bay SAV Distribution Restoration Tier I and Tier III Targets by Chesapeake Bay Program Segment.

CBP Segment	1990 SAV Distribution (Hectares)	Tier I SAV Restoration Target (Hectares)	1990 SAV Distribution as a Percentage of the Tier I SAV Restoration Target	Tier III SAV Restoration Target (Hectares)	1990 SAV Distribution as a Percentage of the Tier III SAV Restoration Target
CB1	1780	3101	57%	6975	26%
CB2	19	139	14%	3086	<1%
CB3	36	817	4%	3426	1%
CB4	5	103	5%	3496	<1%
CB5	4981	6309	79%	15083	33%
CB6	511	783	65%	2923	17%
CB7	3112	4624	67%	11803	26%
CB8	29	86	34%	1928	2%
WT1	0	24	0%	1836	0%
WT2	87	353	25%	3056	3%
WT3	3	349	<1%	839	<1%
WT4	0	0	0%	1061	0%
WT5	0	53	0%	1452	0%
WT6	0	240	0%	838	0%
WT7	0	189	0%	883	0%
WT8	0	78	0%	1970	0%
TF1	0	6	0%	890	0%
RET1	0	16	0%	959	0%
LE1	0	132	0%	2653	0%
TF2	1642	3098	53%	8304	20%
RET2	1367	1847	74%	7443	18%
LE2	51	282	18%	18012	<1%
TF3	0	0	0%	3293	0%
RET3	0	0	-	5928	0%
LE3	401	1714	23%	9342	4%
TF4	0	0	-	1614	0%
RET4	0	0	-	2915	0%
LE4	79	309	26%	4822	2%
WE4	4192	5902	71%	12529	33%
TF5	0	0	-	5780	0%
RET5	0	13	0%	4987	0%
LE5	3	16	19%	13841	<1%
ET1	0	7	0%	1207	0%
ET2	364	467	78%	2967	12%
ET3	39	167	24%	1515	3%
ET4	33	1506	2%	5812	<1%
ET5	0	191	0%	3009	0%
ET6	0	0	-	4082	0%
ET7	0	0	-	2648	0%
ET8	103	271	38%	3763	3%
ET9	128	363	35%	2044	6%
ET10	0	0	-	495	0%
EE1	391	2474	16%	8815	4%
EE2	188	3646	5%	11648	2%
EE3	4849	6350	76%	35686	14%
TOTALS	**24393**	**46025**	**53%**	**247658**	**10%**


Chesapeake Bay SAV Distribution
Restoration Target – Tier III

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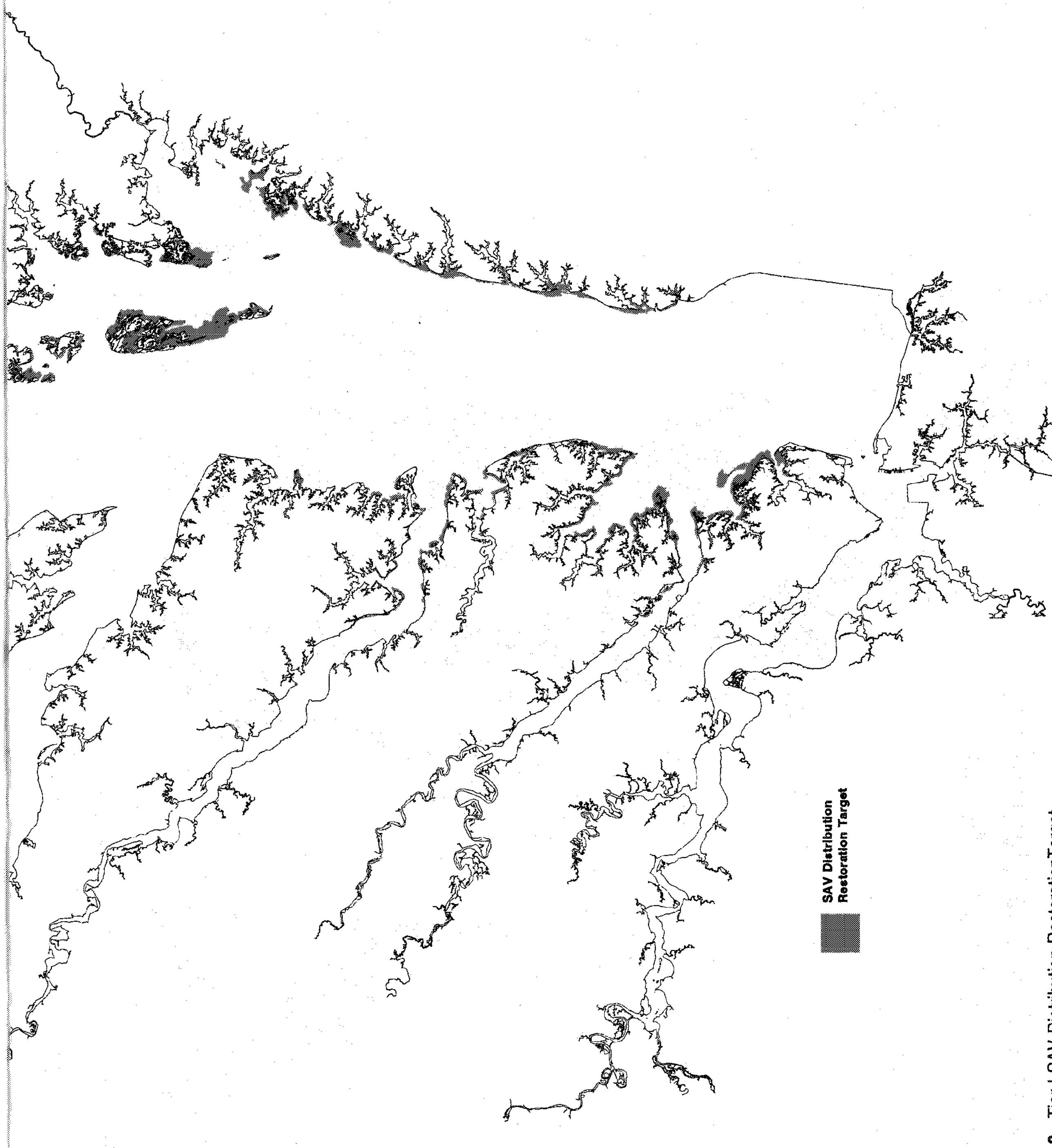
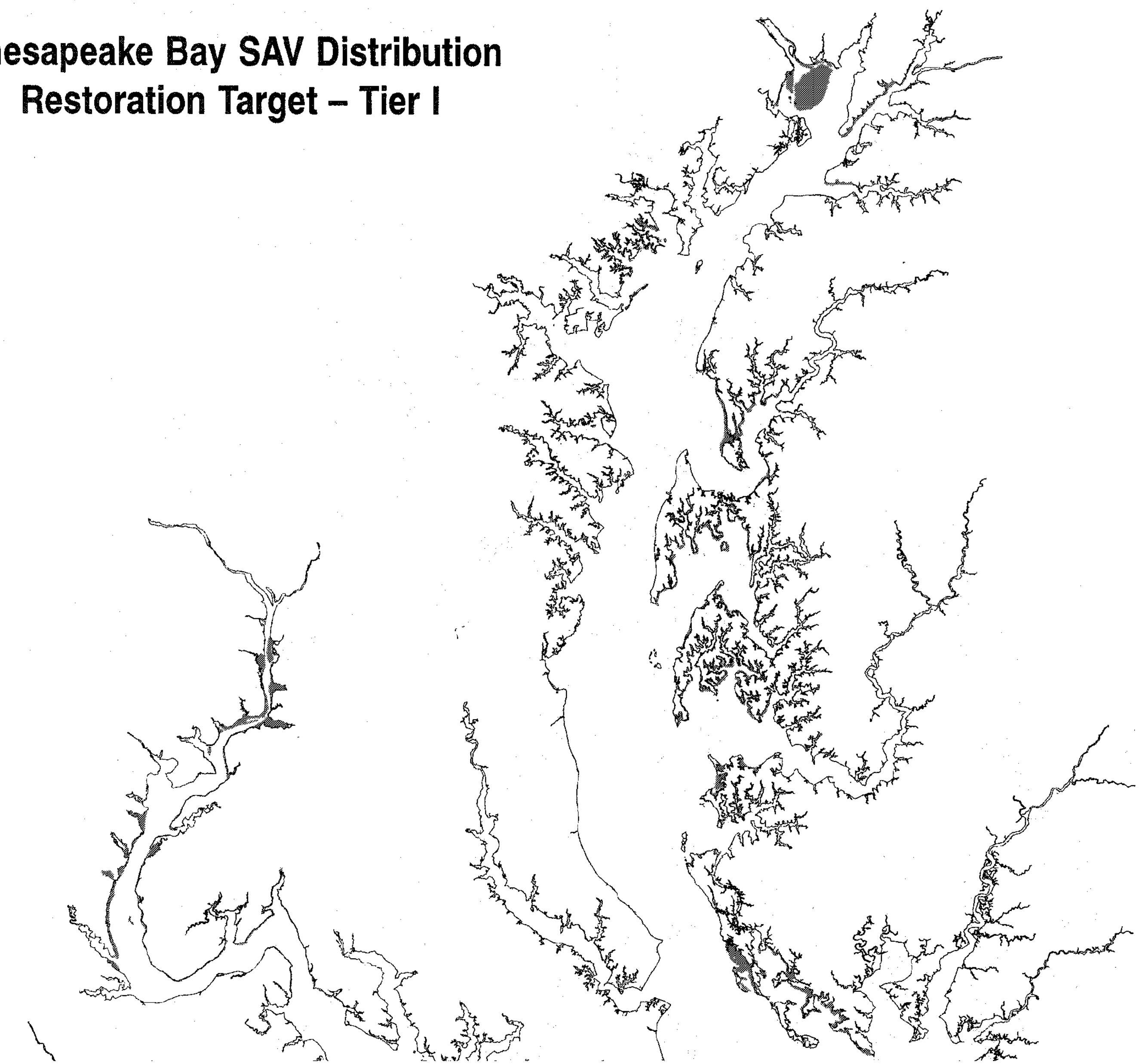


Figure VI-3. Tier I SAV Distribution RestorationTarget.

Chesapeake Bay SAV Distribution
Restoration Target – Tier I



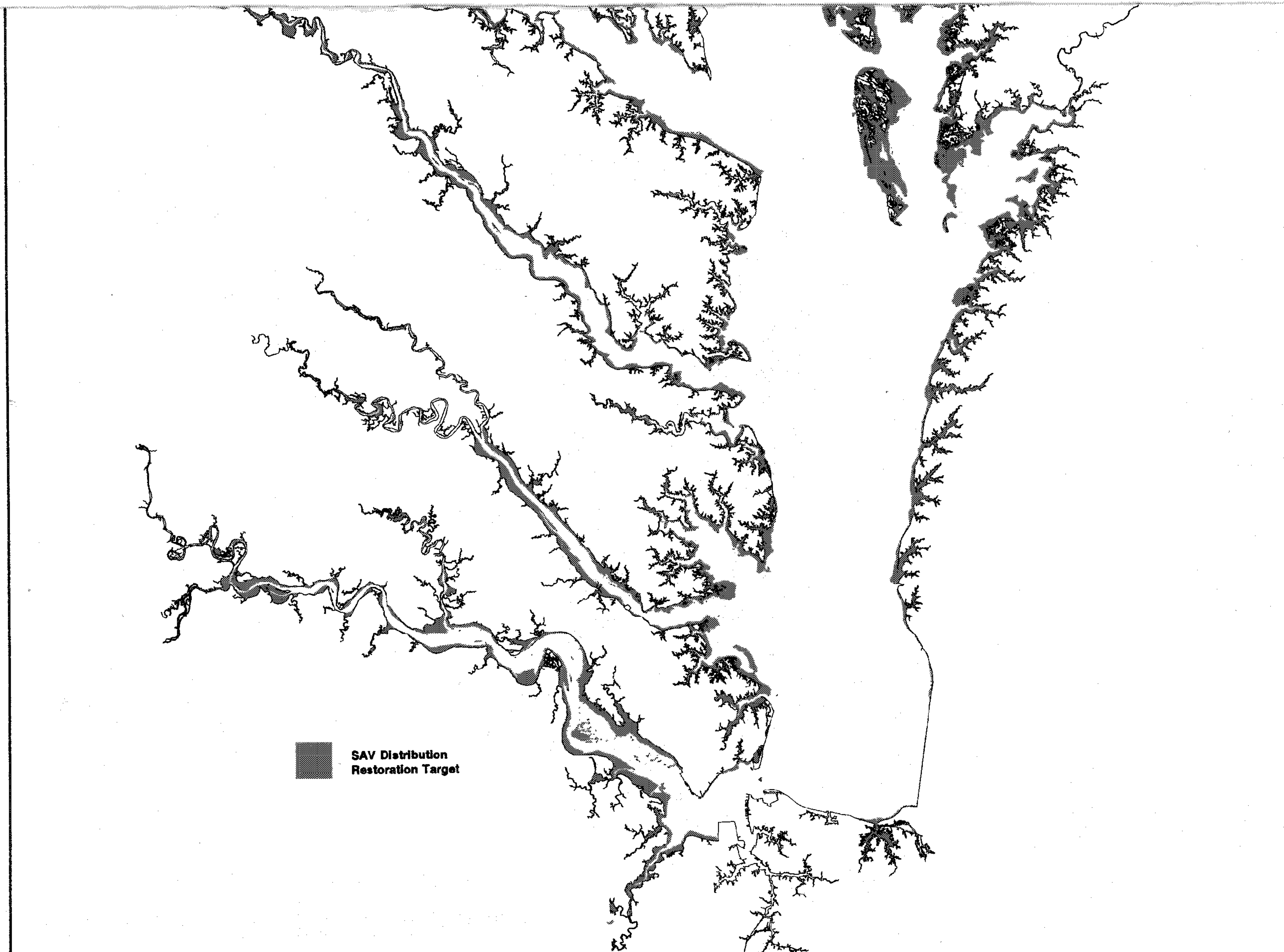


Figure VI-4. Tier III SAV Distribution RestorationTarget.

SAV propagules. These areas are predominantly in the mainstem of Chesapeake Bay (e.g., the shoreline between the mouth of the Potomac and Patuxent rivers). Tier II also excludes areas where extensive physical disruption of the shoreline and nearshore habitat would prevent SAV from reestablishing (e.g., certain areas in the Hampton Roads and Baltimore Harbor regions). Achievement of this SAV distribution restoration target will also depend on the presence of sufficient propagules. In addition, other environmental factors limiting growth and reproduction (e.g., salinity, temperature, sediment substrate, and herbicides) must be within the general tolerance limits of the SAV species.

Tier III Goal: *Restoration of SAV to all shallow water areas delineated as existing or potential SAV habitat down to the two meter depth contour.*

Achievement of this SAV distribution target depends on achievement of the SAV habitat requirements for two meter restoration for light penetration (Table IV-1) and aims for SAV growth down to two meters in depth. Tier III includes all areas in Tiers I and II as well as all areas delineated within the two meter depth contour in Chesapeake Bay and its tributaries. Tier III excludes the same areas as Tier II as well as some selected areas within the one-two meter depth contour where primarily wave exposure will limit SAV growth to the one meter depth contour. Achievement of this SAV distribution restoration target will also depend on the presence of sufficient propagules. In addition, other environmental factors limiting growth and reproduction (e.g., salinity, temperature, sediment substrate, and herbicides) must be within the general tolerance limits of the SAV species.

A total of 46,025 hectares of SAV has been mapped as comprising the Tier I target. The 1990 estimate of SAV abundance indicates that the current levels of SAV are 53% of Tier I. Areas with greater than 50% of the target are CB1–57% (Northern Chesapeake Bay), CB5–79% (Lower Chesapeake Bay), CB6–65% (Western Lower Chesapeake Bay), CB7–67% (Eastern Lower Chesapeake Bay), TF2–53% (Upper Potomac River), RET2–74% (Middle Potomac River), ET2–78% (Elk/Bohemia rivers), WE4–71% (Mobjack Bay), and EE3–76% (Tangier Sound). Although the two upper Bay segments that include the Susquehanna Flats region have high percentages, 95% of the vegetation area is very sparse and has remained sparse during the aerial surveys. These segments historically supported some of the densest stands of SAV in the Bay. Today, the large area of the Flats supports only sporadic patches of one species (M. Spicatum); whereas in the past, dense, continuous, multi-species beds were present (Bayley *et al.* 1978). Thus, the density and species diversity targets for this region are below the expected targets. Surprisingly, a large number of species are found in the many fringing beds in this region but most are dominated by one or a few species (Orth and Nowak 1990; Orth *et al.* 1991).

Interestingly, the rapid expansion of *H. verticillata* in the upper Potomac River and the upper portion of the middle Potomac River in the 1980s has contributed to the vegetation of a relatively large area of the potential habitat. Although *H. verticillata* is the numerically dominant species in the Potomac, many of the areas inshore of the *H. verticillata* beds are vegetated with numerous other SAV species (Orth and Nowak 1990; Orth *et al.* 1991).

Based on Tier I targets, SAV is doing best in the lower mainstem Bay segments (CB5, CB6, CB7, and EE1) where water quality conditions are better than upper Bay or upper tributary areas. In particular, SAV is notably absent, or in very reduced abundance, in many of the upper western shore tributaries (WT1–Bush River, WT2–Gunpowder River, WT3–Middle River, and WT8–South/West/Rhodes rivers), many of the eastern shore tributaries (ET1–Northeast River, ET4–Chester River, ET5–Choptank River, ET6–Nanticoke River, ET7–Wicomico River, and ET10–Pocomoke River), the Patuxent River (TF1, RET1, and LE1), the lower Potomac River (LE2), the middle and upper York River (RET4, TF4), and the James River (LE5, RET5, and TF5). Of the five major western shore tributaries, the James and Patuxent rivers have the least amount of SAV.

Delineation of the Bay bottom for the Tier III target showed 247,659 hectares of potential habitat within the two meter depth contour. The 1990 SAV distribution indicates that the current levels are only 10% of the target for Tier III. Areas with greater than 10% of the target are CB1–25% (Northern Chesapeake Bay), CB5–33% (Lower Chesapeake Bay), CB6–18% (Western Lower Chesapeake Bay), CB7–26% (Eastern Lower Chesapeake Bay), TF2–20% (Upper Potomac River), RET2–18% (Middle Potomac River), ET2–12% (Elk/Bohemia rivers), WE4–34% (Mobjack Bay), and EE3–14% (Tangier Sound). As with Tier I, the greatest proportion of Tier III target achievement was in the lower Bay segments where water quality conditions are better.

There are two additional considerations for the application of the tiered distribution restoration targets. First, the tiers, as presented, do not take into account the density of SAV in a segment. For example, a large bed

Table VI-4. Chesapeake Bay SAV Density Restoration Targets Status by Chesapeake Bay Program Segments.

CBP Segment	1990 SAV Distribution (Hectares)	1990 SAV Distribution (and%) within 70-100% Density Category (Hectares)		Tier I SAV Restoration Target (Hectares)	1990 SAV Distribution within 70-100% Density Category as Percentage of Tier I SAV Restoration Target
CB1	1780	84	(5%)	3101	3%
CB2	19	0	(0)%	139	0%
CB3	36	<1	(1%)	817	1%
CB4	5	0	(0%)	103	0%
CB5	4981	1512	(30%)	6309	24%
CB6	511	303	(59%)	783	39%
CB7	3112	1412	(45%)	4624	31%
CB8	29	<1	(1%)	86	1%
WT1	0	0	(-)	24	0%
WT2	87	27	(31%)	353	8%
WT3	3	0	(0%)	349	0%
WT4	0	0	(-)	0	0%
WT5	0	0	(-)	53	0%
WT6	0	0	(-)	240	0%
WT7	0	0	(-)	189	0%
WT8	0	0	(-)	78	0%
TF1	0	0	(-)	6	0%
RET1	0	0	(-)	16	0%
LE1	0	0	(-)	132	0%
TF2	1642	1187	(72%)	3098	38%
RET2	1367	824	(60%)	1847	45%
LE2	51	5	(10%)	282	2%
TF3	0	0	(-)	0	-
RET3	0	0	(-)	0	-
LE3	401	50	(13%)	1714	3%
TF4	0	0	(-)	0	-
RET4	0	0	(-)	0	-
LE4	79	60	(76%)	309	19%
WE4	4192	2635	(63%)	5902	45%
TF5	0	0	(-)	0	-
RET5	0	0	(-)	13	0%
LE5	3	3	(100%)	16	19%
ET1	0	0	(-)	7	0%
ET2	364	0	(0%)	467	0%
ET3	39	0	(0%)	167	0%
ET4	33	1	(3%)	1506	1%
ET5	0	0	(-)	191	0%
ET6	0	0	(-)	0	0%
ET7	0	0	(-)	0	0%
ET8	103	0	(0%)	271	0%
ET9	128	53	(41%)	363	15%
ET10	0	0	(-)	0	0%
EE1	391	5	(1%)	2474	1%
EE2	188	33	(18%)	3646	1%
EE3	4849	3047	(63%)	6350	48%
TOTALS	**24393**	**11243**	**(46%)**	**46025**	**24%**

in the Susquehanna Flats which has SAV but at a very low density (<10 % or a density class of 1) (see Orth *et al.* 1991 for a description of density classes) would carry the same weight as a very dense bed (>70 % coverage or a density class of 4) (see density restoration section). Second, the tiered approach does not incorporate aspects of species diversity (see species restoration section). For example, a part of a segment that historically contained two or more species would be valued the same today if only one species currently existed there. As progress toward SAV restoration is reviewed, progress toward all three sets of restoration targets for distribution, density, and species distribution/diversity should be examined concurrently.

Chesapeake Bay SAV Density Restoration Targets

For all habitat areas delineated within the SAV distribution restoration targets, the SAV density restoration target is to maximize the amount of SAV coverage present within the 70-100% density category of the crown density scale used in the Chesapeake Bay SAV Aerial Survey (Orth *et al.* 1991). Table VI-4 presents a comparison of the 1990 baywide aerial survey depth with the Chesapeake Bay SAV density restoration target.

The 1990 SAV distributional survey delineated 11,243 hectares of bottom that were classified as dense (70-100% coverage based on Orth *et al.* 1991), or 46% of the total SAV mapped for the Bay and tributaries in 1990. This

Table VI-5. Species of SAV found in Chesapeake Bay and its tidal tributaries.

Family	Species	Common Name
Characeae	*Chara braunii* Gm.	Muskgrass
	Chara zeylanica Klein ex Willd., em.	
	Nitella flexilis (L). Ag., em	
Potamogetonaceae	*Potamogeton perfoliatus*, L. var. bupleuroides (Fernald) Farwell	Redhead grass
	Potamogeton pectinatus L.	Sago pondweed
	Potamogeton crispus L.	Curly pondweed
	Potamogeton pusillus L.	Slender pondweed
	Potamogeton amplifolius	
	Potamogeton diversifolius	
	Potamogeton epihydrus	
	Potamogeton gramineus	
	Potamogeton nodosus	
Ruppiaceae	*Ruppia maritima* L.	Widgeongrass
Zannichelliaceae	*Zannichellia palustris* L.	Horned pondweed
Najadaceae	*Najas guadalupensis* (Sprengel) Magnus	Southern naiad
	Najas gracillima (A. Braun) Magnus	Naiad
	Najas minor Allioni	
	Najas muenscheri	
	Najas flexilis	
Hydrocharitaceae	*Vallisneria americana* Michaux	Wild celery
	Elodea canadensis (Michaux)	Common elodea
	Egeria densa Planchon	Water-weed
	Hydrilla verticillata (L.f.) Boyle	Hydrilla
Pontedariaceae	*Heteranthera dubia* (Jacquin) MacMillian	Water stargrass
Ceratophyllaceae	*Ceratophyllum demersum* L.	Coontail
Trapaceae	*Trapa natans* L.	Water chestnut
Haloragaceae	*Myriophyllum spicatum* L.	Eruasian water milfoil
Zosteraceae	*Zostera marina* L.	Eelgrass

Classification and nomenclature derived from: Godfrey and Wooten, 1979, 1981; Harvill *et al.* 1977, 1981; Kartesz and Kartesz, 1980; Radford *et al.* 1968; Wood and Imahori, 1965.
Sources: Brush 1987; Brush and Hilgartner 1989; Carter *et al.* 1985a; Davis 1985; Hurley 1990; Maryland DNR unpublished data; Orth and Nowak 1990; Orth *et al.* 1979; Chesapeake Bay Program, unpublished data; Paschal *et al.* 1982; R. Younger Personal Communication; Rybicki *et al.* 1988, 1987, 1986; Stevenson and Confer 1978.

represents 24% of the SAV Density Restoration Target for the SAV I SAV Distribution Restoration Target. Areas with significant coverage in this density class are CB5–24% (Lower Chesapeake Bay), CB6–39% (Western Lower Chesapeake Bay), WE4–45% (Mobjack Bay), EE3–48% (Tangier Sound), TF2–38% (Upper Potomac River), and RET2–44% (Middle Potomac River). These data for the density restoration targets contrast with the Tier I target percentages since several of the segments, despite high percentages towards achievement of Tier I, had sparse coverage and thus much lower estimates for the density restoration target–notably the upper Chesapeake Bay area for the Susquehanna Flats and the Elk and Bohemia rivers. All the segments with the highest percentages in the density restoration targets were along both the eastern and western shores of the lower Chesapeake Bay, reflecting the better water quality in the mainstem of the Bay, and in the Potomac River, where *H. verticillata* and other native species have rapidly recolonized the shoals over the last seven years.

Chesapeake Bay SAV Species Distribution/Diversity Restoration Targets

Species Distribution/Diversity Restoration Targets Development Approach

Targets for Chesapeake Bay SAV species distribution/diversity restoration were developed based on both present and historical SAV distribution patterns. Species distribution information included in this analysis was synthesized from surveys of present SAV distribution, surveys from past pollen and seed records, and the literature (listed in Appendix C) which is summarized below.

- SAV aerial survey database made by ground survey and habitat monitoring programs conducted by USGS, Harford Community College, Maryland's Charterboat Captain survey, U.S. Fish and Wildlife Service Citizen Hunt program, University of Maryland Horn Point Environmental Laboratory (HPEL) surveys, and Virginia Institute of Marine Science (VIMS) ground surveys (as reported in Orth *et al.* 1985, 1986, 1987, 1989, 1991; Orth and Nowak 1990).
- Maryland Department of Natural Resources SAV Ground Survey of 644 stations including physical characteristics of the water column, bed biomass, and density.
- U.S. Geological Survey Potomac River Estuary Program Data Reports.
- Pollen and seed record of the upper Bay including the Choptank River and Furnace Bay (Davis 1985; Brush 1987; Brush and Hilgartner 1989).
- The U.S. Fish and Wildlife Service summary of all available SAV information from 1877 to 1978 detailing findings from research, surveys, and historical trend analyses (Stevenson and Confer 1978).

A comprehensive, cumulative listing of all SAV species by Chesapeake Bay segment, documented in the available literature and in the Chesapeake Bay Program Computer Center database, was then compiled and documented by information source (Appendix C, Table C-1). SAV species were recorded for each Chesapeake Bay Program segment based on estimates from maps and site descriptions. Where survey regions overlapped more than one segment, SAV species were assigned to all affected segments.

The Chesapeake Bay species distribution/diversity targets presented by Chesapeake Bay Program segment in Appendix C (Table C-2) were developed based on information compiled in Appendix C, Table C-1 and the potential species distribution maps for the most common Chesapeake Bay SAV species (Figures VI-5 through VI-16).

A total of 28 SAV species are presently found in the Chesapeake Bay and tributaries (Table VI-5), including three species of *Characeae* which are not true rooted species. Twelve species are found most commonly; their distributional limits ultimately determined by salinity. *Zostera marina* is dominant in the more saline, lower reaches of the Bay. *Myriophyllum spicatum, Potamogeton pectinatus, Potamogeton perfoliatus, Zannichellia palustris, Vallisneria americana, Elodea canadensis, Ceratophyllum demersum, H. verticillata, Najas guadalupensis,* and *Heteranthera dubia* are less tolerant of high salinities and are found in the middle and upper reaches of the Chesapeake Bay. *Ruppia maritima* is tolerant of a wide range of salinities and is found from the Bay's mouth to the Susquehanna Flats. The other species listed in Table VI-5 are found only occasionally, and if present, occur primarily in the middle and upper reaches of the Chesapeake Bay and its tidal tributaries.

The SAV community associations of the Chesapeake Bay are an important factor in setting SAV species distribution/diversity restoration targets. These associations are based on a variety of parameters to which members of a particular community are equally tolerant. In an extensive survey of

SAV in the lower Chesapeake Bay, Orth *et al.* (1979) distinguished three plant associations based on the co-occurrence of species in particular habitats. These associations are best explained by their location and salinity. *Z. marina* and *R. maritima* compose the primary association in the lower, higher salinity portions of the Chesapeake Bay. *M. spicatum, P. pectinatus, P. perfoliatus, Z. palustris,* and *V. americana* form the second association and are common in areas where salinities are generally less than 15 parts per thousand (ppt), while *E. canadensis, C. demersum,* and *N. guadalupensis* form the association that is found primarily in freshwater. *H. verticillata* was not in the Bay in 1978 nor is it found in the lower Bay tributaries today, but it would most likely be a member of the freshwater association. Thus, the process of setting SAV species distribution/diversity targets must incorporate the relationship of the different species in the formation of community types.

Species Distribution/Diversity Restoration Targets

Recent (Orth *et al.* 1989; Orth and Nowak 1990) and potential distributional limits for the twelve most common species recorded in the SAV aerial and ground survey programs are presented as individual species distribution restoration targets in Figures VI-5 through VI-16. Achievement of these SAV species specific distribution restoration targets through repropagation to their distributional limits (salinity tolerances) are based on meeting the SAV habitat requirements for one and two meter restoration on a bay-wide basis and the presence of sufficient propagules.

Below is a brief discussion for each of the twelve most common Bay SAV species including a map of overlaying recent species distribution with the species distribution restoration target. The scale of the individual species distribution restoration target maps is such that the exact species distribution has not been delineated and appears to include waters deeper than 2 m. The maps included here are only intended to outline approximate species distributions and should be overlaid onto the smaller scale tiered SAV distribution restoration goal maps for purposes of delineating a more detailed extent of the species distribution /diversity targets. When all these maps are combined, they provide additional documentation for the SAV species distribution/diversity targets for Chesapeake Bay (presented by Chesapeake Bay Program segment in Appendix C, Table C-2).

Zostera marina

Z. marina (eelgrass) is the only true seagrass found in Chesapeake Bay. It has a salinity tolerance of 10-35 ppt, limiting it to the more saline portions of the Chesapeake Bay. Historically, *Z. marina* has grown in the lower sections of the major tributaries on the Bay's lower western shore, including the James, York, Piankatank, Rappahannock, Potomac, and Patuxent rivers. It had been found along the Virginia and Maryland Eastern Shore up to the Eastern Bay area just south of the Chesapeake Bay Bridge. Seed records for this species in the upper Bay are rare, occurring primarily in the lower Patuxent River (Brush and Hilgartner 1989). Seeds occurred sporadically for 200 years in pre-colonial times and did not show appreciable changes in numbers from 1720 until 1880. Between 1930 and 1980, seeds occurred in small numbers, attributable in part to sampling artifacts; however, personal records have indicated the presence of *Z. marina* adjacent to Solomons Island through 1970. Since the 1970s, it has been absent in the entire Patuxent River (Boynton, UMCBL, personal communication). *Z. marina* was last reported in the Patuxent River in 1971 through the U.S. Fish and Wildlife survey (Stevenson and Confer 1978).

Presently, *Z. marina* is abundant along the Eastern Shore from Cape Charles to Smith Island with the largest beds concentrated between Tangier and Smith islands, Great Fox Islands, Big Marsh at the mouth of Chesconessex Creek, and along the major creeks entering the Bay from Chesconessex Creek to Cape Charles. It is abundant on the western shore in Back and Poquoson rivers, off Plum Tree Island, the lower York River on the north shore, Mobjack Bay, and in the Fleets Bay area just above the mouth of the Rappahannock River. It is completely absent from the Potomac and Patuxent rivers, occurs in only one small area in the lower James River, is substantially reduced in the Piankatank and Rappahannock rivers, and is abundant in the lower York only from Gloucester Point to the mouth along the north shore (Orth and Nowak 1990, Orth *et al.* 1991).

Z. marina has increased in abundance in some areas that were either close to beds that never declined (e.g., the lower York River) or in areas where successful transplanting has occurred (e.g., the lower Piankatank and Rappahannock rivers) (Orth and Nowak 1990). Figure VI-5 is a map of the recent distribution overlaid with the *Z. marina* distribution restoration target for Chesapeake Bay.

Hydrilla verticillata

H. verticillata (hydrilla) did not occur in the Chesapeake Bay or tributaries until 1982 when it was first recorded near Dyke Marsh in the upper Potomac River (Stewart *et al.* 1984). Beginning in 1983, *H. verticillata* spread rapidly in the Potomac River and is now found in dense stands on both sides of the river down to Aquia Creek. Approximately 2000 hectares of the river bottom contain *H. verticillata* (Orth and Nowak 1990, Orth *et al.* 1991). Interestingly, *H. verticillata* declined in some areas in 1989, notably in the upper tidal river (Orth and Nowak 1990, Orth *et al.* 1991) presumably due to cooler than normal spring weather, above average rainfall, and poor water clarity. Because of its recent introduction, there is no seed record.

H. verticillata can tolerate salinities up to 6 ppt (Carter *et al.* 1987). *H. verticillata* has also been recorded in the Susquehanna Flats (Kollar, HCC, personal communication) where it grows mixed with other SAV species in small patches. There is no information on when and how it had become established nor is there any indication that it has been spreading at the rates documented for the Potomac River. *H. verticillata's* salinity tolerance would limit its distribution to the upper portions of all tributaries and the upper Bay above the Chesapeake Bay Bridge (Figure VI-6). Because *H. verticillata* is an exotic and recent introduction to Chesapeake Bay (and in some situations considered a nuisance), a restoration target was not established for this species.

Myriophyllum spicatum

M. spicatum (Eurasian watermilfoil) is another exotic species that was introduced into the United States from Asia or Europe in the early 1900s. It is tolerant of slightly brackish waters up to approximately 10 ppt with optimal growth occurring between 0 and 5 ppt (Stevenson and Confer 1978). During the 1950s and early 1960s, this species underwent a still unexplained rapid expansion in the upper Bay and tributaries, including the Potomac and Patuxent rivers. It was considered a major nuisance as it partially obstructed waterways (similar to the hydrilla situation occurring today in the Potomac River). It was estimated that *M. spicatum* covered more than 100,000 acres during this period. As rapidly as it expanded, *M. spicatum* also declined in the mid-1960s. Scientists attributed the decline to a viral-like disease, although the proof was never conclusive. A seed record for this species was available only from the Susquehanna Flats (Brush and Hilgartner 1989). Seeds were present from 1930 to 1970, mirroring the changes recorded in distribution surveys.

Today, *M. spicatum* is present primarily in large stands in the upper Potomac River, including the Port Tobacco River and Nanjemoy Creek, and is found interspersed with *H. verticillata* above Aquia Creek (Carter *et al.* 1983, 1985). It is also found in much smaller areas in the Susquehanna Flats, the Sassafras River, and the Saltpeter and Seneca Creek region on the western shore. *M. spicatum* has been commonly reported from many other areas by the Citizens and Charterboat Captains surveys throughout its upper Bay distributional range (Orth and Nowak 1990, Orth *et al.* 1991). Given its growth potential, *M. spicatum* has the ability to occupy much more available habitat in the upper Bay as well as the upper sections of all the tributaries and creeks (Figure VI-7).

Ruppia maritima

R. maritima (widgeongrass) has the widest salinity tolerance of all SAV species in the Bay and is able to survive equally well in hypersaline lagoons as well as low salinity brackish bays and estuaries. Although this species can survive in freshwater, it has not been reported to inhabit tidal fresh sections of the Bay. Given this salinity range tolerance, *R. maritima* has one of the greatest potential distribution limits of all Bay SAV.

The seed record for *R. maritima* has showed a continuous record from pre-colonial times with abundance of seeds declining in the 20th century (Brush and Hilgartner 1989). Seed distribution has been restricted to the downstream, mesohaline portions of the tributaries, similar to current distributional patterns. The period of 1720-1820 had the greatest number of seeds while 1970-1987 was the period of least seed abundance.

Presently, *R. maritima* is normally found in close association with *Z. marina* in the lower Bay. Generally, *R. maritima* is found in the shallow portions of a bed and intertidally while *Z. marina* dominates the deeper sections, with both species found at intermediate depths (Orth and Moore 1988).

Shown by the seed record, *R. maritima* declined in the 1960s and 1970s along with many of the other species. Beginning around 1985, *R. maritima* began to recover naturally in many sections of the Bay. By 1989, the species had shown major increases in the lower Rappahannock, Piankatank, and Potomac rivers, and in the mid-sections of the Bay along the Eastern Shore including Eastern Bay, the Choptank River, and the Barren Island-Honga River area (Carter *et al.* 1983, 1985; Orth and Nowak 1990). This species was the most often cited species in many of the late

1980s surveys. Presently, this species may occupy more bottom area than any other species.

R. maritima is considered an opportunistic species with an extremely rapid growth rate and large seed production. The lack of any other competitor SAV species may have allowed this species to spread rapidly. Its wide salinity range and past historical record indicate that *R. maritima* could grow in shallow water areas throughout the Bay (Figure VI-8).

Heteranthera dubia

Surprisingly, *H. dubia* (water stargrass) was not reported in Chesapeake Bay or its tidal tributaries until the 1980s. Seeds have not been reported in the historical record (Brush and Hilgartner 1989). A freshwater species, it has been reported as a commonly occurring species only in the Susquehanna Flats and tidal fresh portions of the Potomac River in the 1980s (Orth *et al.* 1989; Orth and Nowak 1990; Kollar, HCC, personal communication; Carter and Rybicki 1986). The ability to tolerate only slightly brackish waters restricts its distributional limits to the tidal fresh or very low salinity areas of the Bay and tributaries (Figure VI-9).

Vallisneria americana

V. americana (wild celery) is one of the more valuable freshwater species in the Bay and tributaries. It is tolerant of water up to 11-13 ppt (Carter and Rybicki, USGS, personal communication; Barko, USCOE, personal communication). The seed record for this species showed it to be abundant in pre-colonial times through 1880 in the upper Bay and tributaries, principally from Furnace Bay, the Back, Middle, Severn, Patuxent, and Chester rivers (Brush and Hilgartner 1989). There was a large increase in seeds from 1880 through 1930 and sporadic occurrences through 1970. From 1970 through 1987, the seed record showed a dramatic decline and was recorded from only one core in the Middle River.

Recent surveys have shown *V. americana* to be most abundant in the Susquehanna River and Flats region and in the tidal fresh, oligohaline, and mesohaline section of the Potomac River (Carter *et al.* 1983, 1985). It has also been reported less frequently from the Elk, Sassafras, Middle, and Gunpowder rivers and many small creeks (Orth and Nowak 1990, Orth *et al.* 1991).

Past distribution of this species indicates that it was one of the more common species in the Bay region, indicating that *V. americana* can potentially occupy much more habitat than it presently occupies (Figure VI-10).

Zannichellia palustris

Z. palustris (horned pondweed) is an annual that, like *R. maritima*, is one of the most widely distributed species in Chesapeake Bay and its tributaries. Based on its present distribution, this species can apparently tolerate salinities up to 20 ppt. The seed record has shown *Z. palustris* to be one of the most persistent species in the oligohaline and mesohaline areas of the upper Bay for the last 2000 years (Brush and Hilgartner 1989). The period of 1720-1880 showed the greatest abundance of seeds, especially in the Severn and Back rivers and Langford and Rock creeks. Between 1880 and 1980, seed abundances fluctuated but the species was consistently present.

Recent distribution studies reported *Z. palustris* to be abundant in the Choptank, Patuxent, Potomac, Back, Middle, Gunpowder, and Rappahannock rivers and the Eastern Bay area (Carter *et al.* 1983, 1985; Orth and Nowak 1990, Orth *et al.* 1991). It is likely that this species is present today in many other areas in much greater abundance than a decade ago. Since this species has been a consistent part of the historical record and has a large seed output with high annual variation, *Z. palustris* will most likely continue growing in the Bay but show a high degree of variability. Figure VI-11 is a map of the recent distribution overlaid with the *Z. palustris* distribution restoration target for Chesapeake Bay.

Najas guadalupensis

N. guadalupensis (southern naiad or bushy pondweed) is the more common of four naiad species found in the Bay. It is tolerant of slightly brackish waters up to 10 ppt. This species was common in the seed record of pre-colonial times but was most abundant from 1720-1880, especially in Langford and Rock creeks and the Chester, Patuxent, Middle, and Back rivers (Brush and Hilgartner 1989). Although seeds were still abundant in the Middle and Patuxent rivers and Langford Creek, a decline in the seed record began in 1880 and continued until 1980. During 1970-1987, seeds were found in some areas such as the Middle and Back rivers but were generally much less abundant, continuing the overall decline that started in the 1880s.

Present surveys have found *N. guadalupensis* primarily in the Susquehanna River and Flats region and in the transition and tidal fresh water zones of the Potomac River (Carter *et al.* 1983, 1985; Orth and Nowak 1990, Orth *et al.* 1991). Ground surveys in the 1980s reported this species in the Choptank and Middle rivers, Rock Creek, and several smaller creeks throughout the Bay. The potential distributional limits are in the upper Bay and upper portions of the major tributaries (Figure VI-12).

Potamogeton perfoliatus

P. perfoliatus (redhead grass) has been another of the more common species previously found in the upper Bay and tributaries. It is a freshwater species that can tolerate salinities up to 20 ppt. The seed record for *P. perfoliatus* shows that this species was common in pre-colonial times, with sporadic occurrences from 1720-1930 (Brush and Hilgartner 1989). The period from 1930-1970 was a period of proliferation after which there was an overall decline, with seeds found only in the Middle and Severn rivers and Langford and Rock creeks.

The most recent ground surveys have reported sporadic occurrences of *P. perfoliatus* throughout the northern Bay and upper portions of tributaries in the northern Bay–in particular the Chester River, Susquehanna River and Flats, and the mid-section of the Potomac River around Mathais Point, Port Tobacco River, and Nanjemoy Creek (Carter *et al.* 1983, 1985; Orth and Nowak 1990, Orth *et al.* 1991). Its high salinity tolerance, compared to several of the other freshwater species, along with its past historical distribution indicate a broader potential distribution for this species (Figure VI-13).

Potamogeton pectinatus

P. pectinatus (sago pondweed) is the second species of this genus found in the Bay and tributaries and has been reported frequently in the past. It is a freshwater species that can tolerate salinities up to 9 ppt. Brush and Hilgartner (1989) do not report on any seed record for this species.

Present distributional surveys have reported this species to be most common in several sections of the Bay–notably the Potomac River from Washington, DC to the Port Tobacco River and Nanjemoy Creek area, the Middle, Chester and Choptank rivers, and the Susquehanna River and Flats area (Carter *et al.* 1983, 1985; Orth and Nowak 1990, Orth *et al.* 1991). *P. pectinatus* has been one of the more frequently reported species in the upper Bay in recent years but is still far below population densities reported earlier. Its presence in many different sections of the upper Bay and its potential distribution limits indicate that this species can occupy a much wider area than many of the other species (Figure VI-14).

Ceratophyllum demersum

C. demersum (coontail or hornwort) is a freshwater species that is capable of tolerating salinities up to 6 ppt. Interestingly, this species grows independently of a particular substrate and can subsist by floating in the water. It normally produces asexually, with fragments easily able to develop into viable shoots. Brush and Hilgartner (1989) do not report on a seed record for this species. The poor record may result from this plant's infrequent production of seeds.

Present distribution of this species is primarily in the Susquehanna River and Flats area, the upper Patuxent River, and the Potomac River transition and tidal freshwater zone (Carter *et al.* 1983, 1985; Orth and Nowak 1990, Orth *et al.* 1991). Since this species is not rooted and can tolerate some brackish water, it could likely have a much wider distribution than present (Figure VI-15). However, the lack of rooting may restrict it to areas with little current movement or to co-occur with other species that are rooted.

Elodea canadensis

E. canadensis (common elodea) is a freshwater species with a salinity tolerance of approximately 10 ppt. This species is a common home aquarium plant and closely resembles hydrilla. It is commonly reported in the Bay region.

E. canadensis had a fairly continuous seed distribution record until colonial settlement (Brush and Hilgartner 1989). There appeared to be an increase in populations from 1720-1880; but between 1880 and 1930, it disappeared from the Severn River and Rock Creek. Between 1930 and 1970 it disappeared from most of Back Creek while at the same time appearing in Langford Creek. Between 1970 and 1987, seeds were found only in the upper Middle River.

Recent distributional surveys have found *E. canadensis* in the Susquehanna River and Flats area, the Chester River region, and the tidal fresh and oligohaline zones of the Potomac River (Carter *et al.* 1983, 1985; Orth and Nowak 1990, Orth *et al.* 1991). Earlier surveys in the 1970s found a more broad distribution than present (Stevenson and Confer 1978), indicating the potential of this species to expand to many other new areas (Figure VI-16).

Chesapeake Bay Distribution Restoration Target for *Zostera marina*

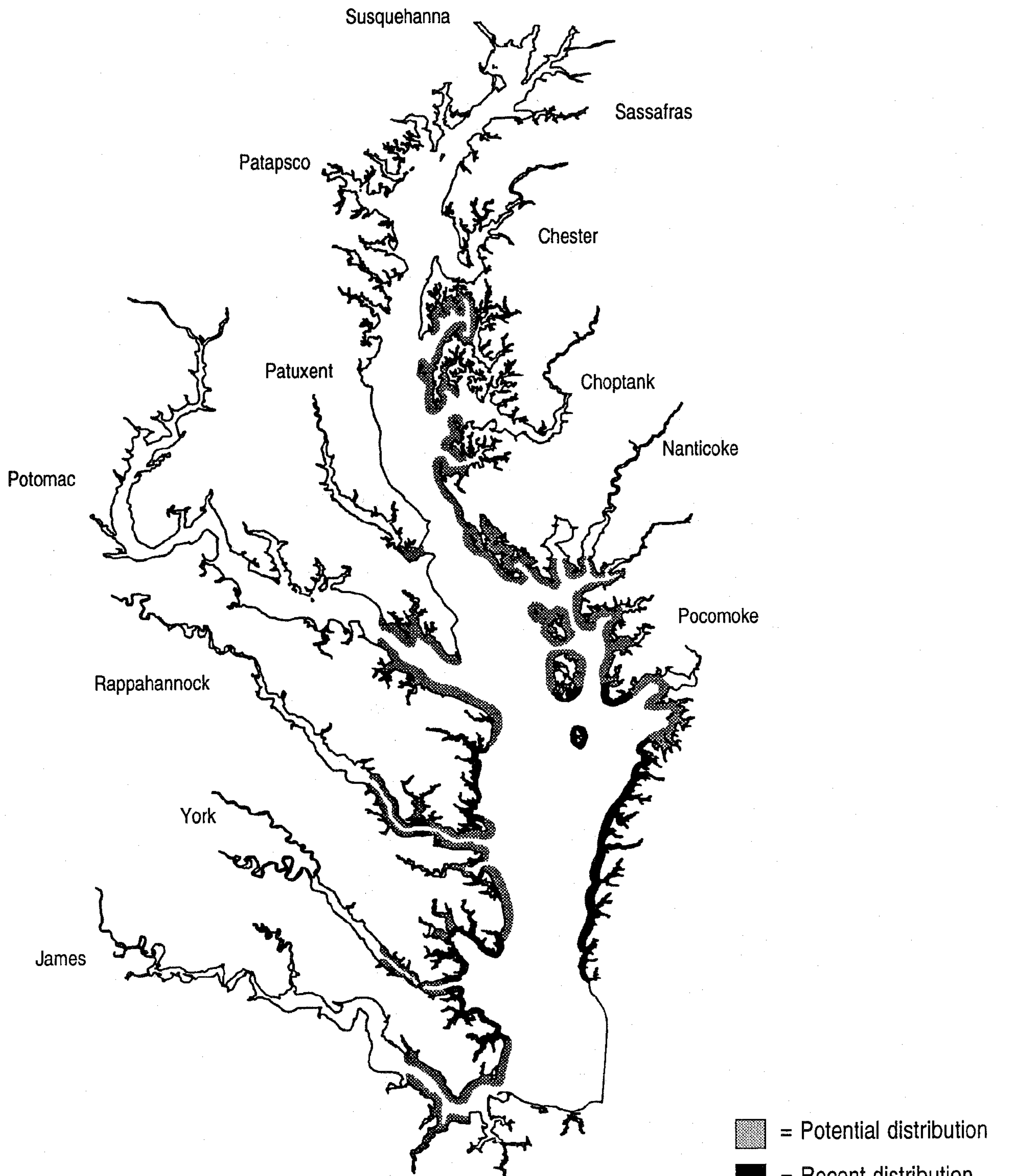


Figure VI-5. Distribution restoration target for *Zostera marina* in Chesapeake Bay is shown as the combined potential and recent species distribution. Some areas deeper than the anticipated depth of SAV growth (2m) are shaded due to the scale of the map; see Figure VI-4 for more accurate distribution depth limits.

Chesapeake Bay Recent and Potential Distribution for *Hydrilla verticillata*

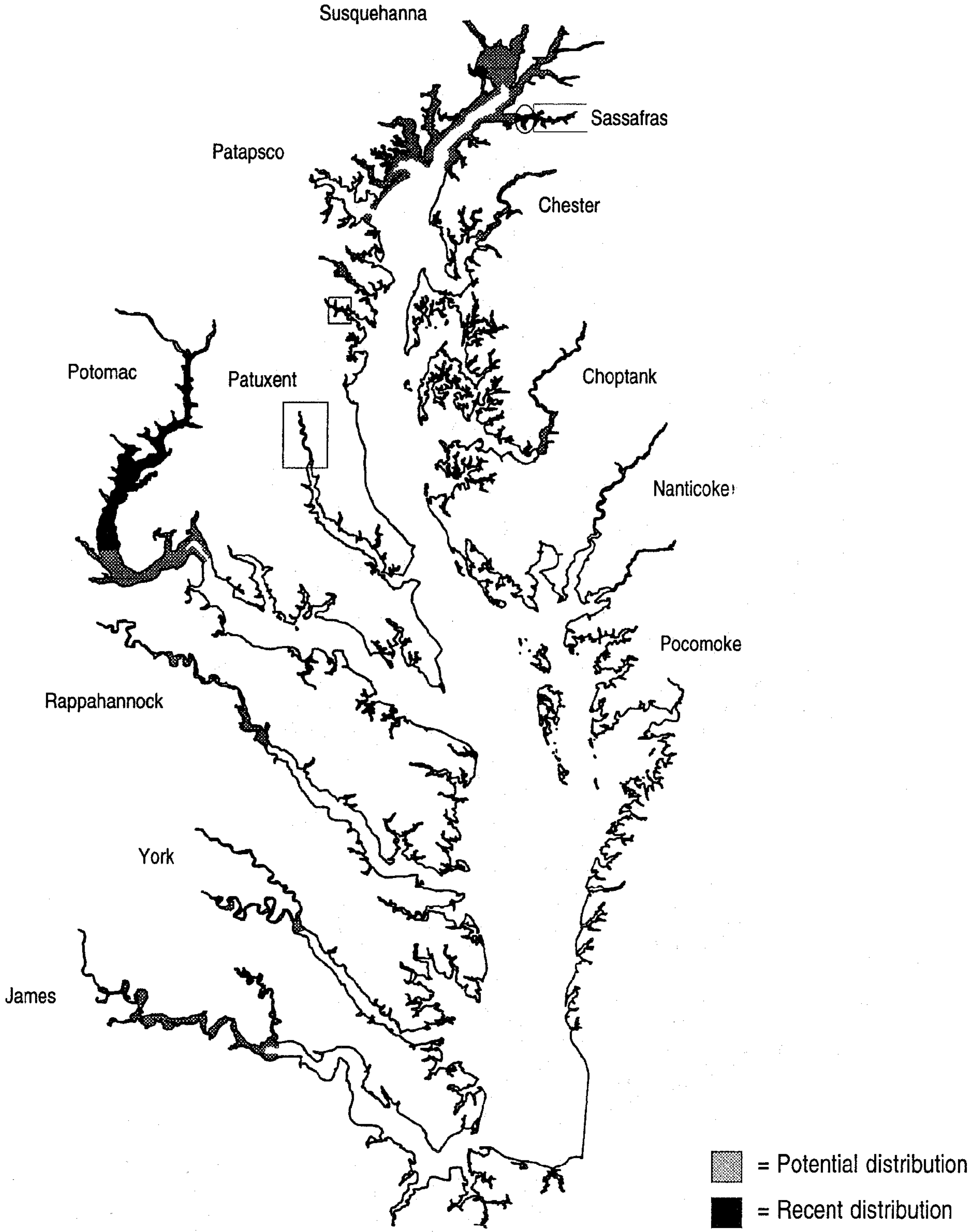


Figure VI-6. Recent and potential distribution of *Hydrilla verticillata* in Chesapeake Bay is shown. Some areas deeper than the anticipated depth of SAV growth (2m) are shaded due to the scale of the map; see Figure VI-4 for more accurate distribution depth limits. The open box (□) and open circle (○) are used to delineate potential and recent distribution, respectively, in sections of the tributaries where the shading patterns are not visible due to the scale of the figure.

Chesapeake Bay Distribution Restoration Target for *Myriophyllum spicatum*

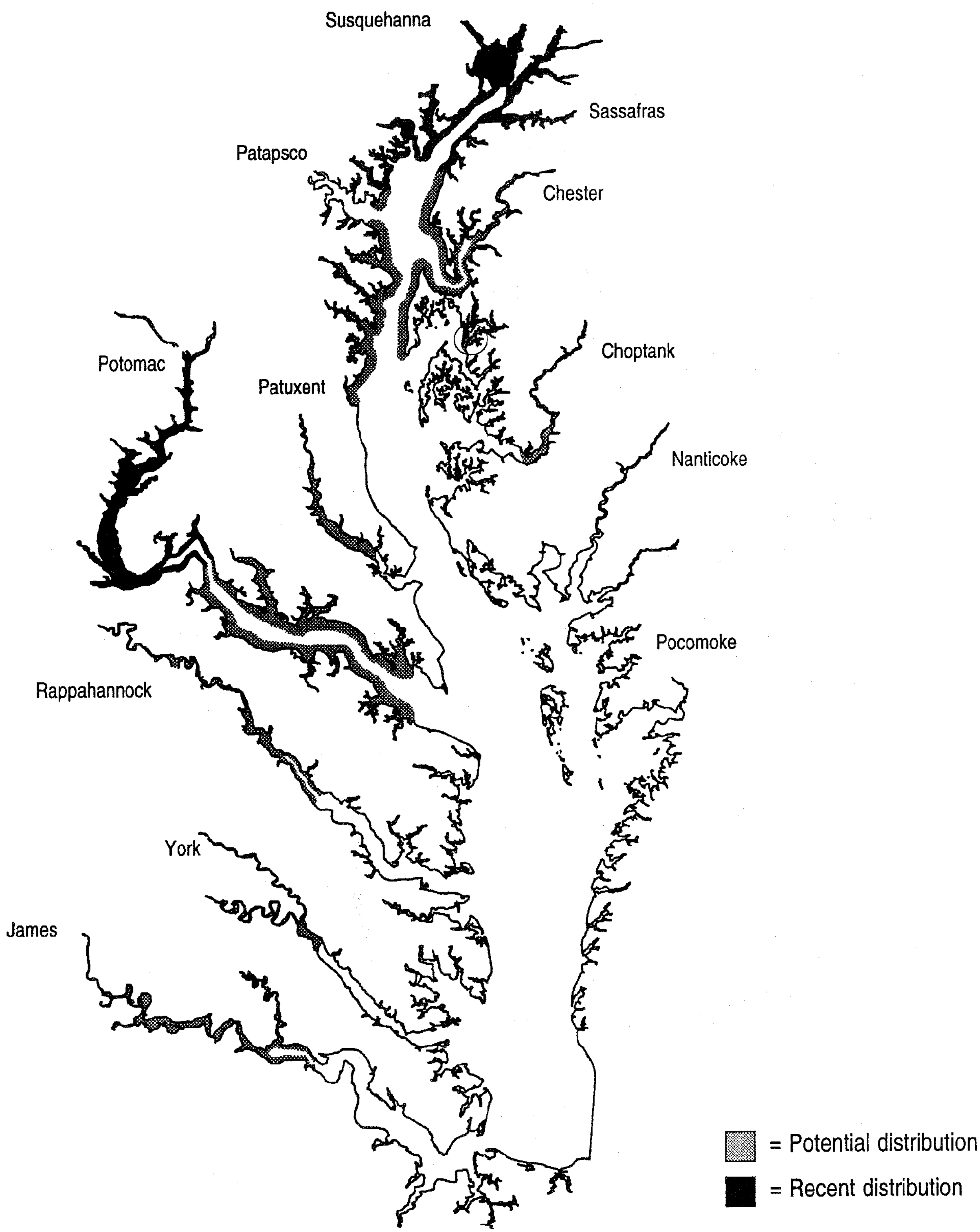


Figure VI-7. Distribution restoration target for *Myriophyllum spicatum* in Chesapeake Bay is shown as the combined potential and recent species distribution. Some areas deeper than the anticipated depth of SAV growth (2m) are shaded due to the scale of the map; see Figure VI-4 for more accurate distribution depth limits.

Chesapeake Bay Distribution Restoration Target for *Ruppia maritima*

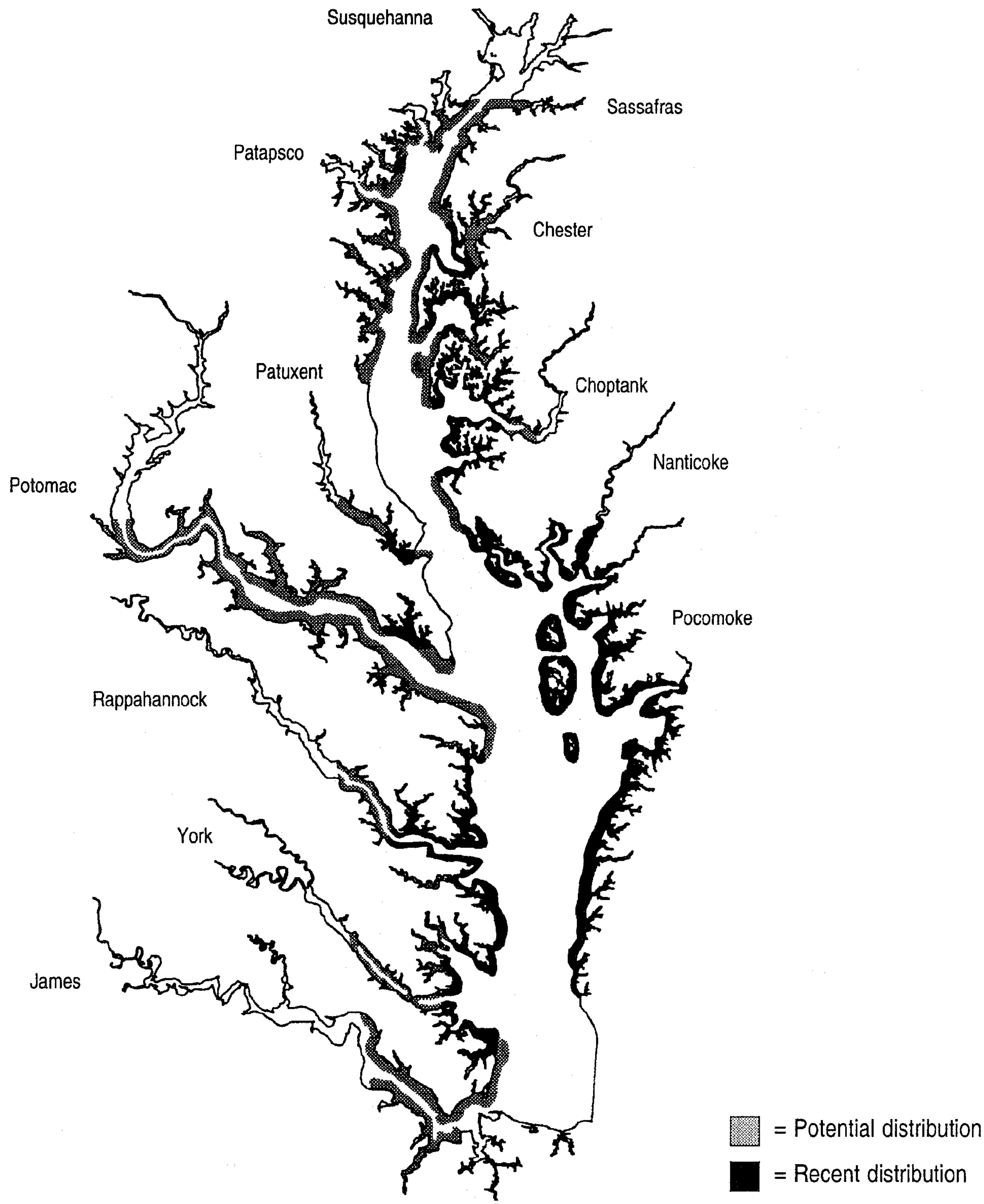


Figure VI-8. Distribution restoration target for *Ruppia maritima* in Chesapeake Bay is shown as the combined potential and recent species distribution. Some areas deeper than the anticipated depth of SAV growth (2m) are shaded due to the scale of the map; see Figure VI-4 for more accurate distribution depth limits.

Chesapeake Bay Distribution Restoration Target for *Heteranthera dubia*

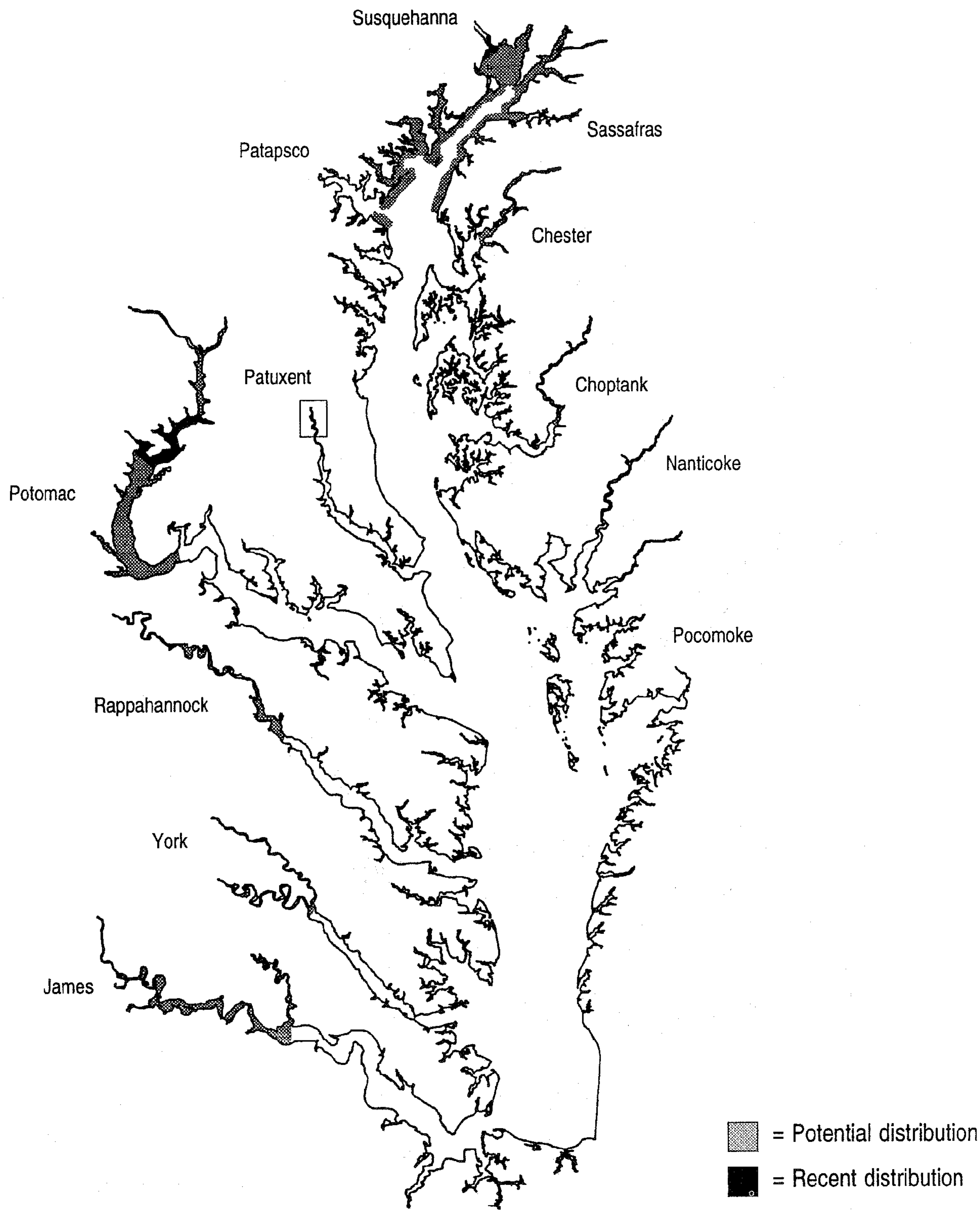


Figure VI-9. Distribution restoration target for *Heteranthera dubia* in Chesapeake Bay is shown as the combined potential and recent species distribution. Some areas deeper than the anticipated depth of SAV growth (2m) are shaded due to the scale of the map; see Figure VI-4 for more accurate distribution depth limits. The open box (☐) is used to delineate potential distribution in sections of the tributaries where the shading pattern is not visible due to the scale of the drawing.

Chesapeake Bay Distribution Restoration Target for *Vallisneria americana*

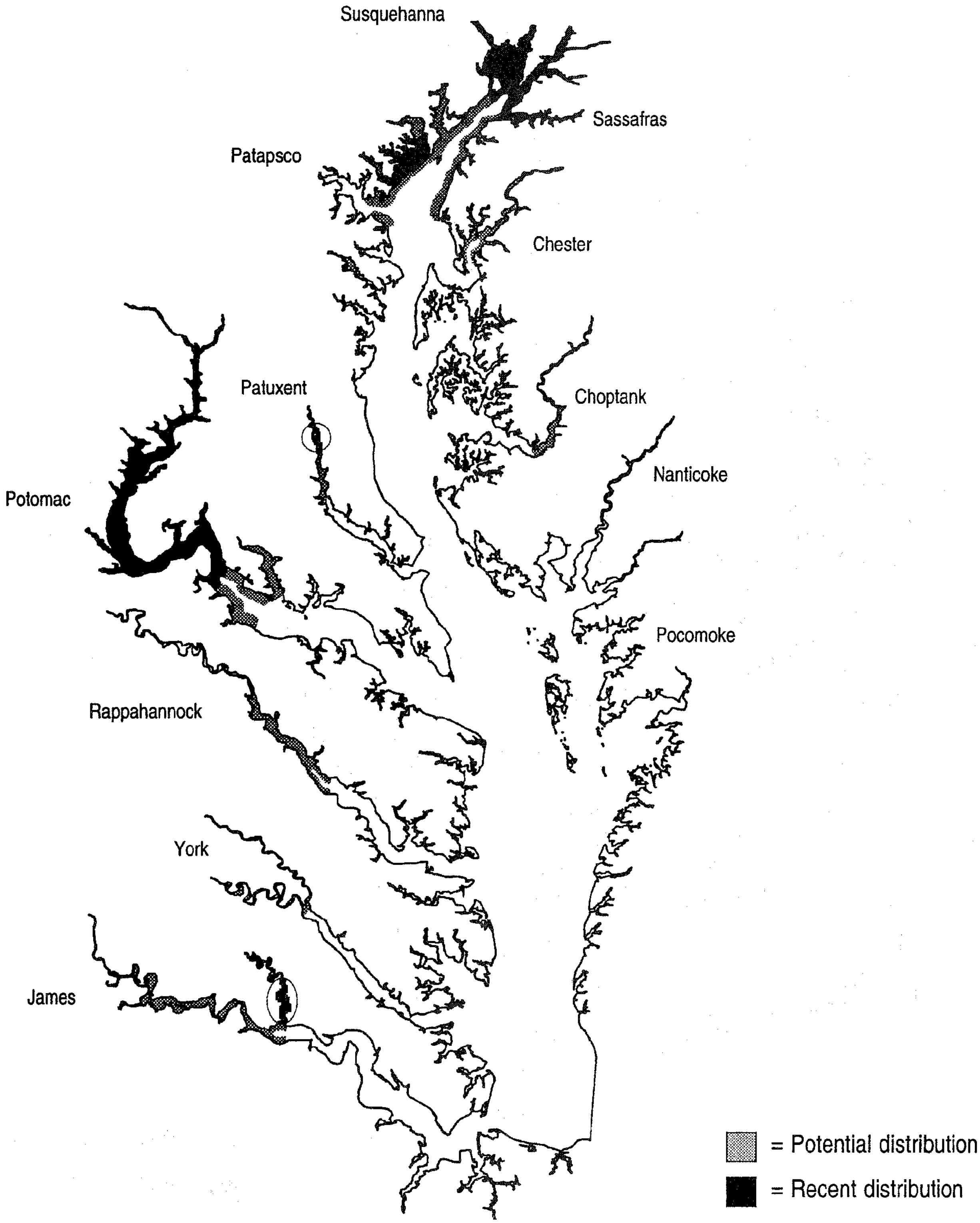


Figure VI-10. Distribution restoration target for *Vallisneria americana* in Chesapeake Bay is shown as the combined potential and recent species distribution. Some areas deeper than the anticipated depth of SAV growth (2m) are shaded due to the scale of the map; see Figure VI-4 for more accurate distribution depth limits. The open circle (○) is used to delineate recent distribution in sections of the tributaries where the shading pattern is not visible due to the scale of the figure.

Chesapeake Bay Distribution Restoration Target for *Zannichellia palustris*

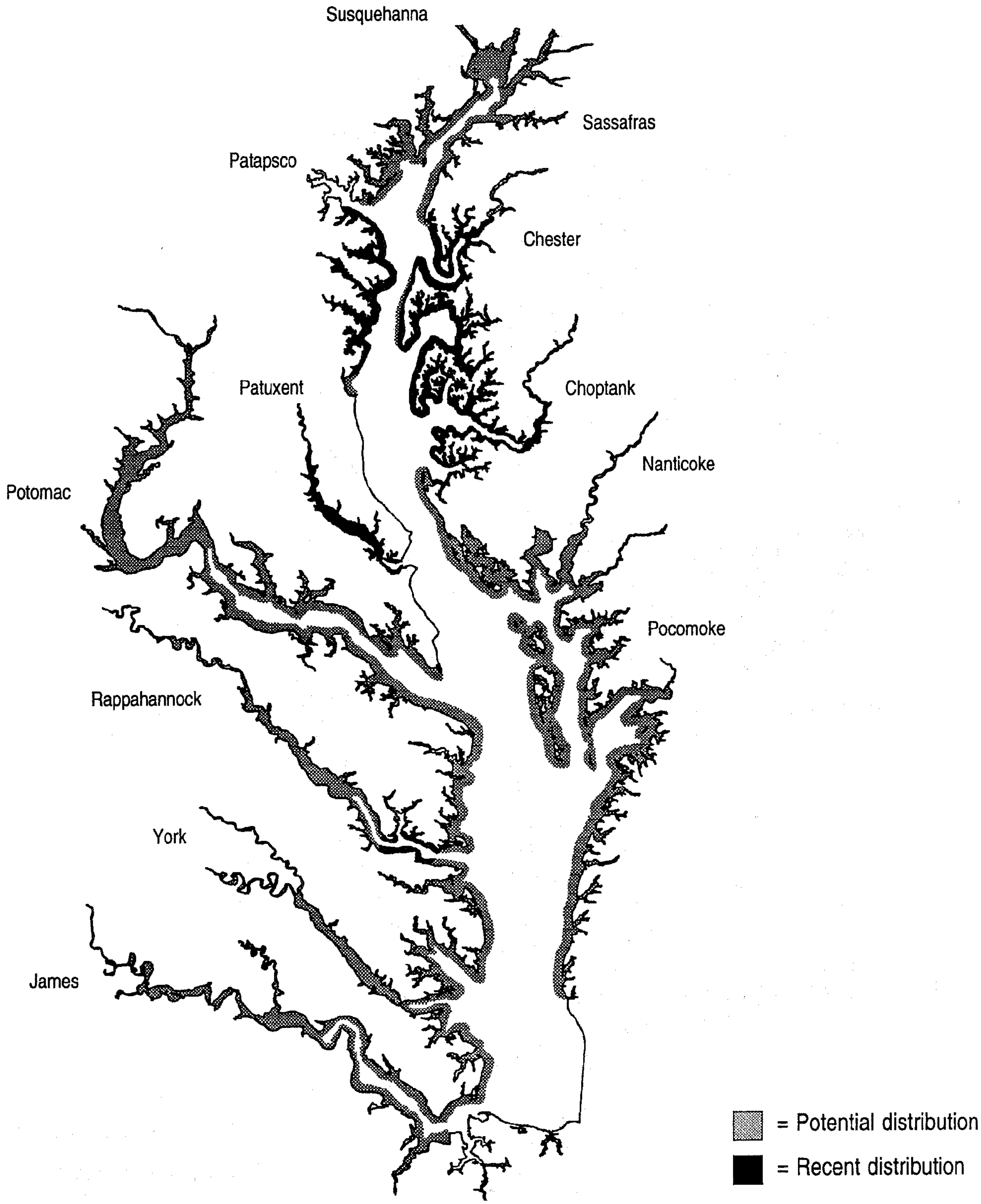


Figure VI-11. Distribution restoration target for *Zannichellia palustris* in Chesapeake Bay is shown as the combined potential and recent species distribution. Some areas deeper than the anticipated depth of SAV growth (2m) are shaded due to the scale of the map; see Figure VI-4 for more accurate distribution depth limits.

Chesapeake Bay Distribution Restoration Target for *Najas guadalupensis*

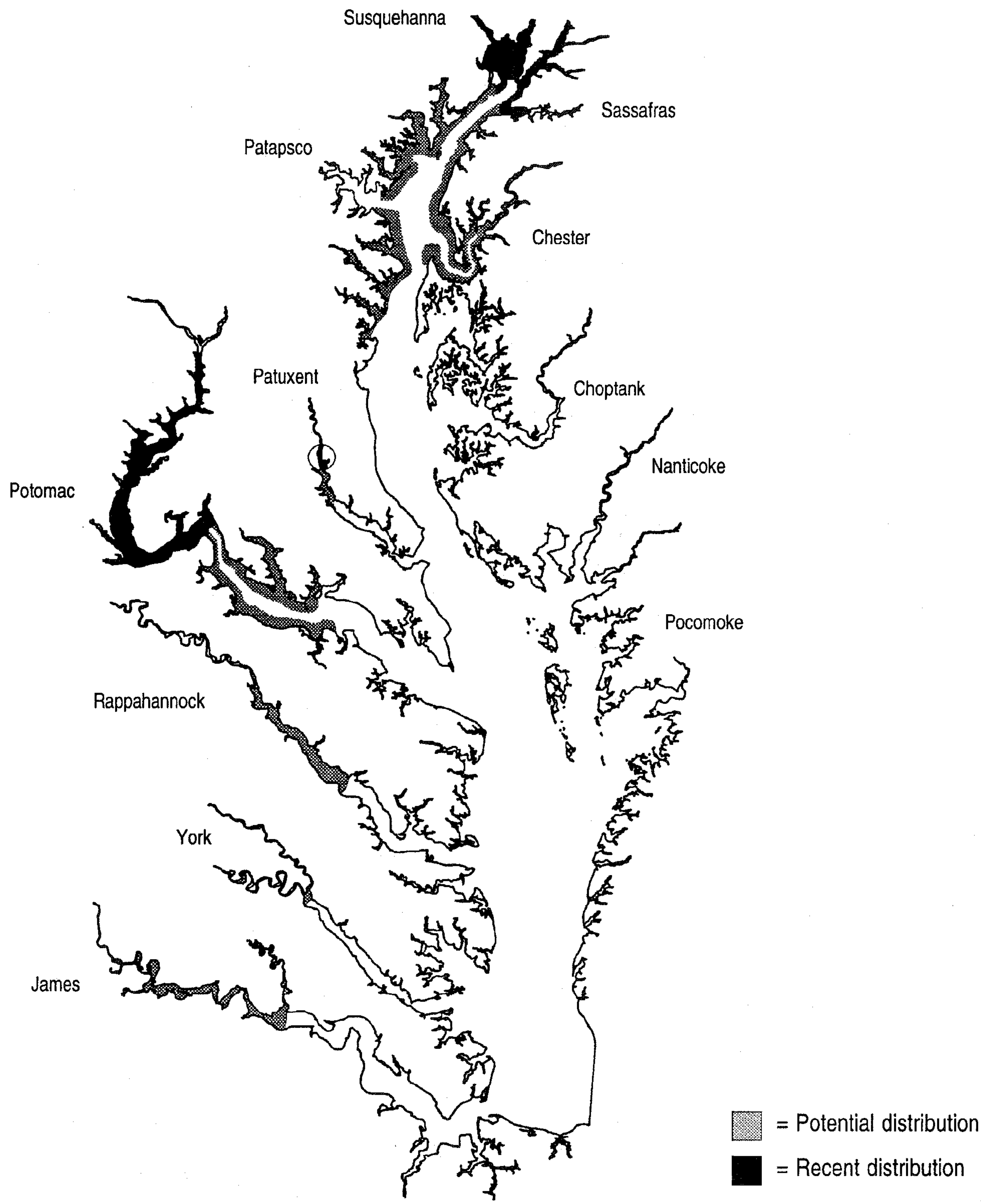


Figure VI-12. Distribution restoration target for *Najas guadalupensis* in Chesapeake Bay is shown as the combined potential and recent species distribution. Some areas deeper than the anticipated depth of SAV growth (2m) are shaded due to the scale of the map; see Figure VI-4 for more accurate distribution depth limits. The open circle (○) is used to delineate recent distribution in sections of the tributaries where the shading pattern is not visible due to the scale of the figure.

Chesapeake Bay Distribution Restoration Target for *Potamogeton perfoliatus*

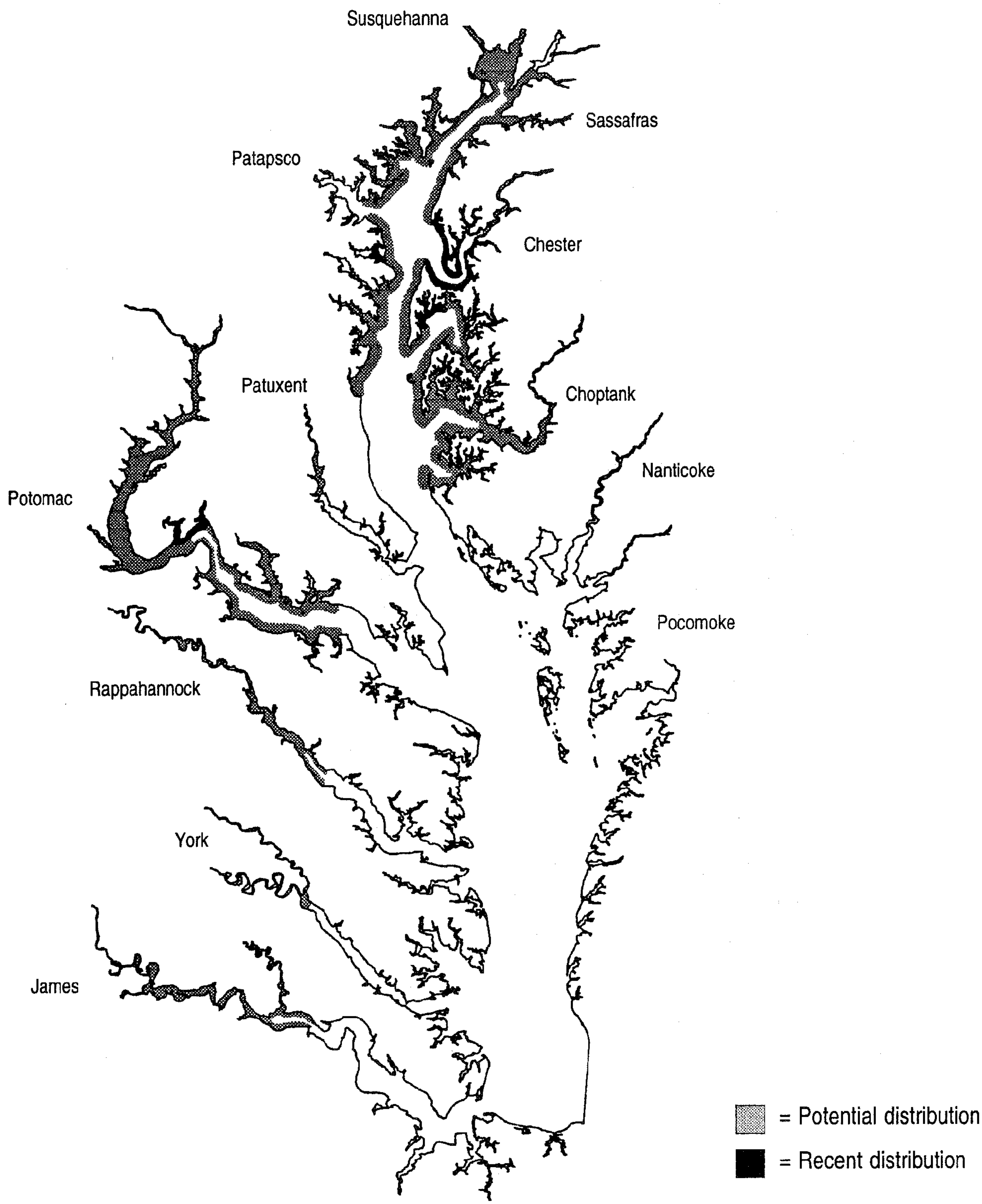


Figure VI-13. Distribution restoration target for *Potamogeton perfoliatus* in Chesapeake Bay is shown as the combined potential and recent species distribution. Some areas deeper than the anticipated depth of SAV growth (2m) are shaded due to the scale of the map; see Figure VI-4 for more accurate distribution depth limits.

Chesapeake Bay Distribution Restoration Target for *Potamogeton pectinatus*

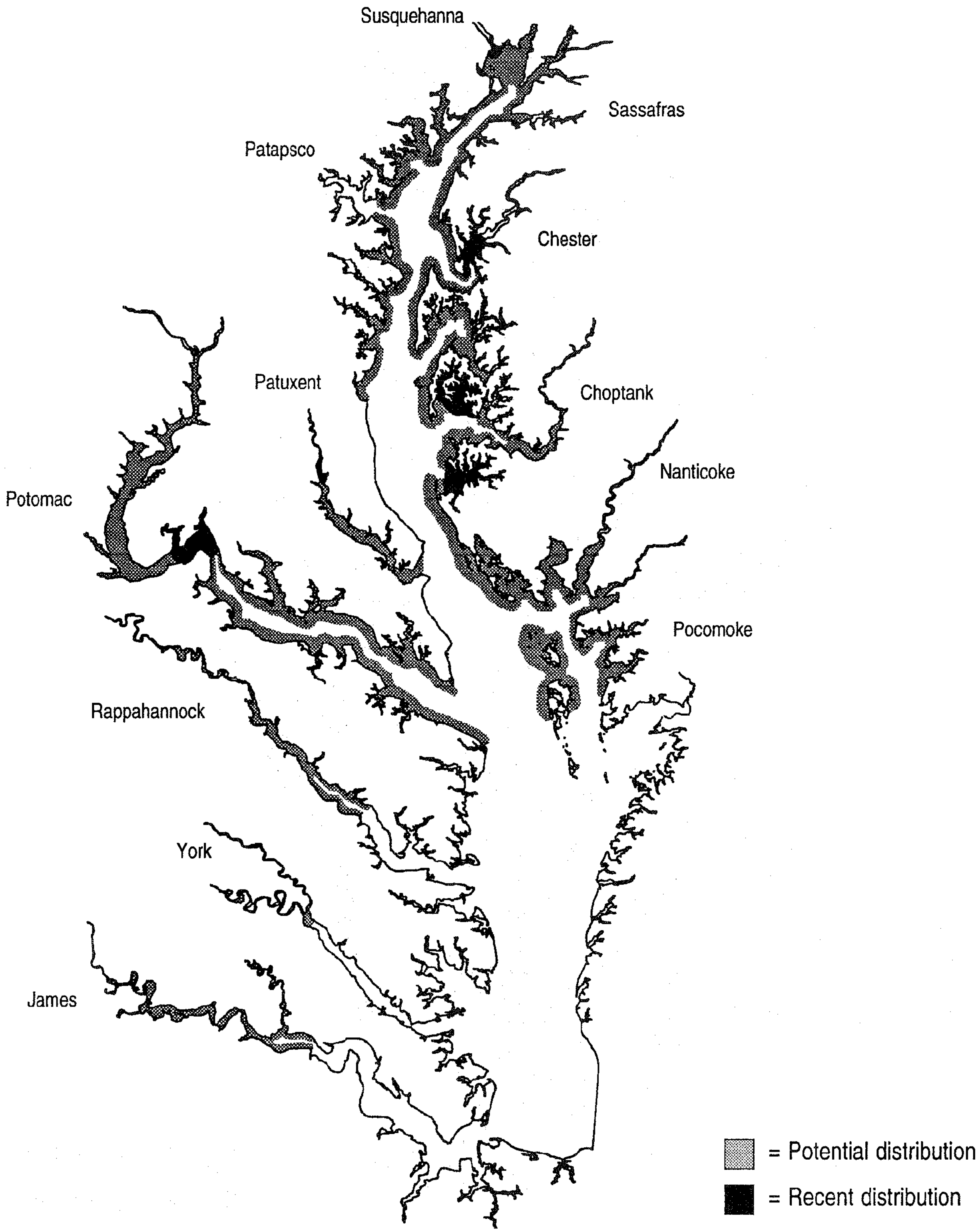


Figure VI-14. Distribution restoration target for *Potamogeton pectinatus* in Chesapeake Bay is shown as the combined potential and recent species distribution. Some areas deeper than the anticipated depth of SAV growth (2m) are shaded due to the scale of the map; see Figure VI-4 for more accurate distribution depth limits.

Chesapeake Bay Distribution Restoration Target for *Ceratophyllum demersum*

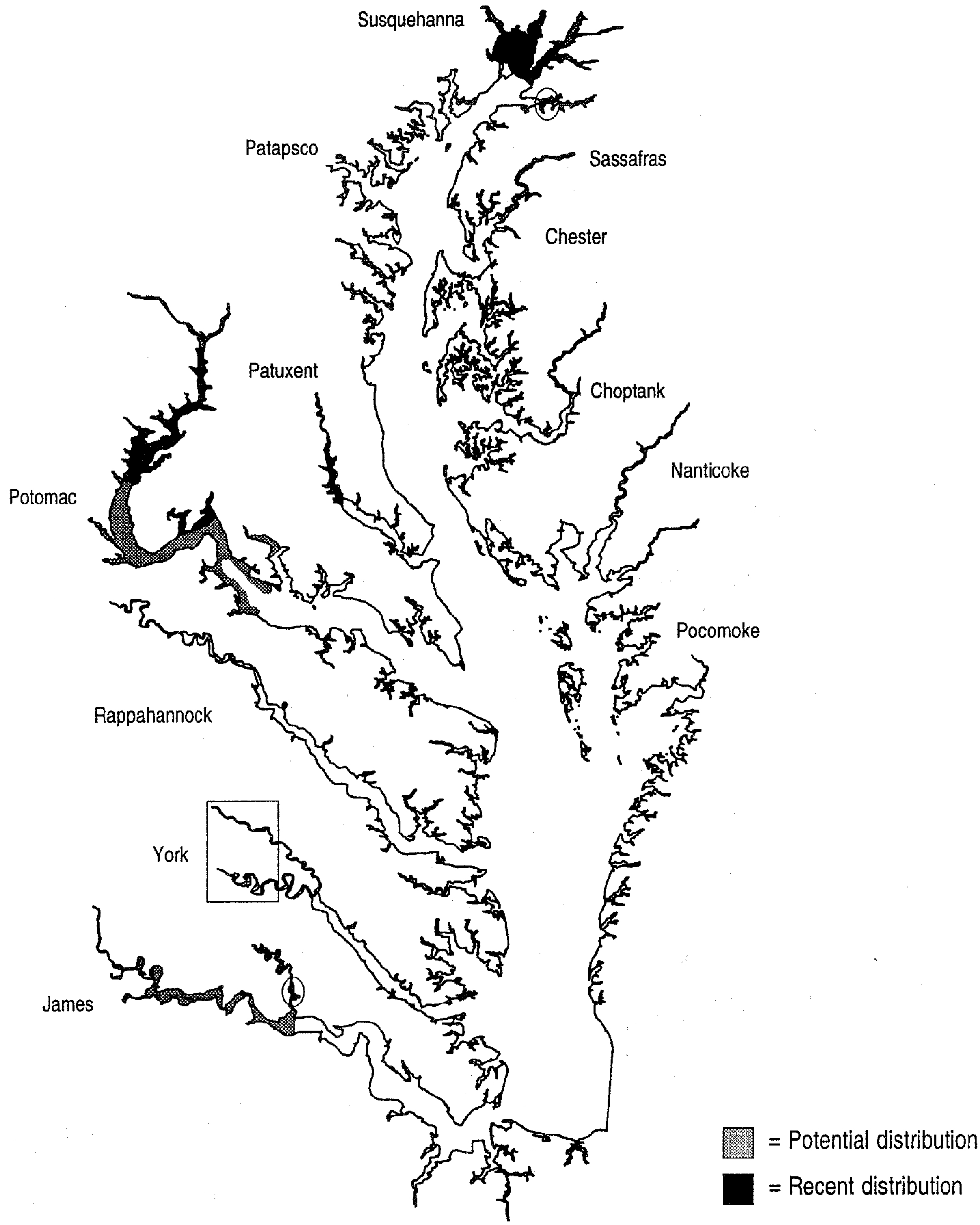


Figure VI-15. Distribution restoration target for *Ceratophyllum demersum* in Chesapeake Bay is shown as the combined potential and recent species distribution. Some areas deeper than the anticipated depth of SAV growth (2m) are shaded due to the scale of the map; see Figure VI-4 for more accurate distribution depth limits. The open box (▢) and open circle (◯) are used to delineate potential and recent distribution, respectively, in sections of the tributaries where the shading patterns are not visible due to the scale of the figure.

Chesapeake Bay Distribution Restoration Target for *Elodea canadensis*

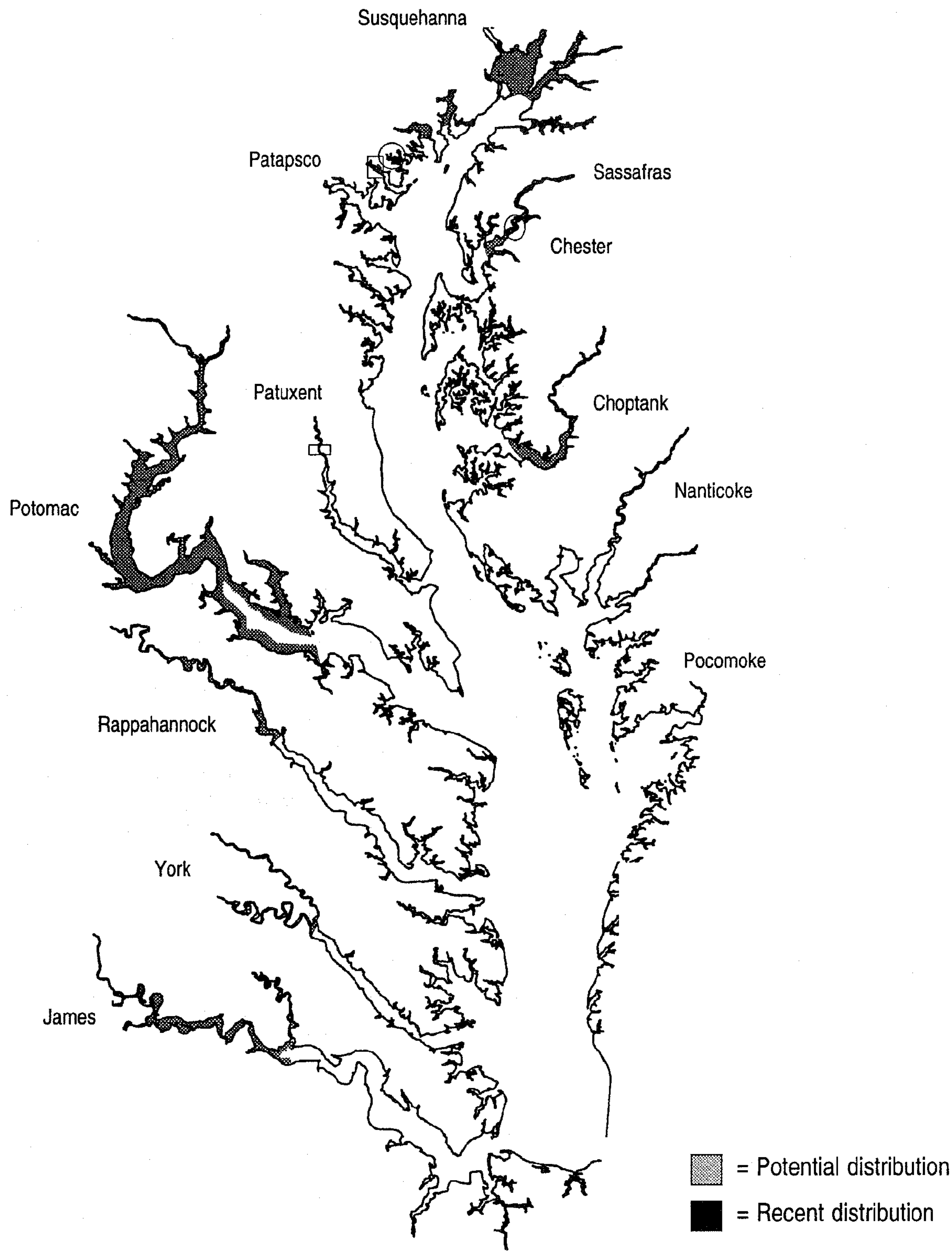


Figure VI-16. Distribution restoration target for *Elodia canadensis* in Chesapeake Bay is shown as the combined potential and recent species distribution. Some areas deeper than the anticipated depth of SAV growth (2m) are shaded due to the scale of the map; see Figure VI-4 for more accurate distribution depth limits. The open box (□) and open circle (◯) are used to delineate potential and recent distribution, respectively, in sections of the tributaries where the shading patterns are not visible due to the scale of the figure.

Chapter VII
Nearshore & Mid-channel Water Quality Comparisons

In the preceding chapters, levels of selected water quality parameters characteristic of viable submerged aquatic vegetation (SAV) habitat in the Chesapeake Bay were defined. The objective of this study is to determine if existing mid-channel water quality data is appropriate for characterizing seasonal water quality conditions in adjacent nearshore areas. If the water quality is comparable, then data from existing mid-channel monitoring programs might be used to determine if water quality conditions are meeting habitat requirements for SAV. In addition, the results will provide guidance for modifying mid-channel monitoring programs or assisting in the development of additional nearshore monitoring programs in areas where nearshore and mid-channel data have proven incomparable.

Study Areas and Sampling Programs

York River

Six stations within the lower 30 kilometers of the York River, three mid-channel and three nearshore, were selected for comparison in this study (Figure VII-1). These areas are representative of polyhaline and mesohaline regions of Virginia's tributaries that currently or historically have supported SAV. The nearshore stations were sampled by the Virginia Institute of Marine Science (VIMS) as part of the Virginia Nearshore Submerged Aquatic Vegetation Monitoring Program. Mid-channel stations LE4.2 and LE4.3 are sampled as part of the Virginia Chesapeake Bay Tributary Water Quality Monitoring Program, and mid-channel station WE4.2 was sampled as part of the Chesapeake Bay Mainstem Water Quality Monitoring Program. Both of the mid-channel station monitoring programs were coordinated by the Virginia State Water Control Board (VSWCB).

Mid-channel data included only those samples obtained at one meter depth or, in some cases, at the surface. Nearshore samples were obtained in triplicate at a depth of 0.25 m. Water column depths in the nearshore at mean low water (MLW) were approximately one meter. The Guinea Marsh and Gloucester Point stations were located in areas vegetated with SAV. The Claybank station was located in a shoal area which formerly supported SAV but is now devoid of vegetation. Characteristics of the York River stations are presented in Table VII-1.

Table VII-1. Characteristics of York River nearshore and mid-channel water quality monitoring stations.

Station	Years	Vegetated	Salinity
Guinea Marsh VIMS nearshore site	1985-1988	Yes	Polyhaline
WE4.2 VSWCB mid-channel site	1985-1988	No	Polyhaline
Gloucester Point VIMS nearshore site	1985-1988	Yes	Polyhaline
LE4.3 VSWCB mid-channel site	1985-1988	No	Polyhaline
Claybank VIMS nearshore site	1985-1988	No	Mesohaline
LE4.2 VSWCB mid-channel site	1985-1988	No	Mesohaline

York River Nearshore and Mid-channel Water Quality Monitoring Stations

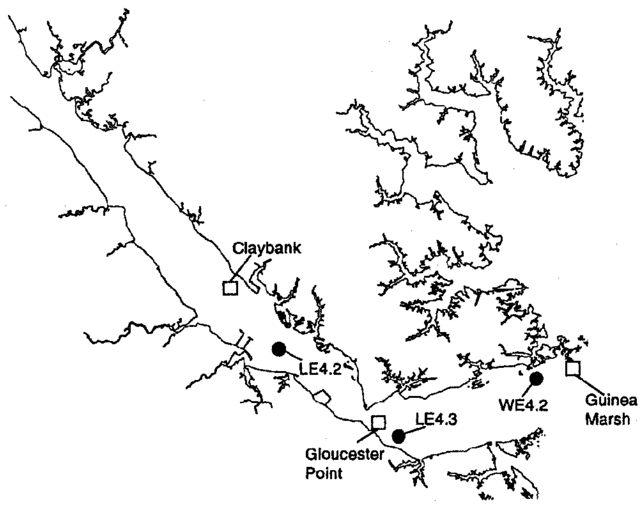


Figure VII-1. York River nearshore (□) and mid-channel (●) water quality monitoring stations used in the data analysis.

Potomac River Nearshore and Mid-channel Water Quality Monitoring Stations

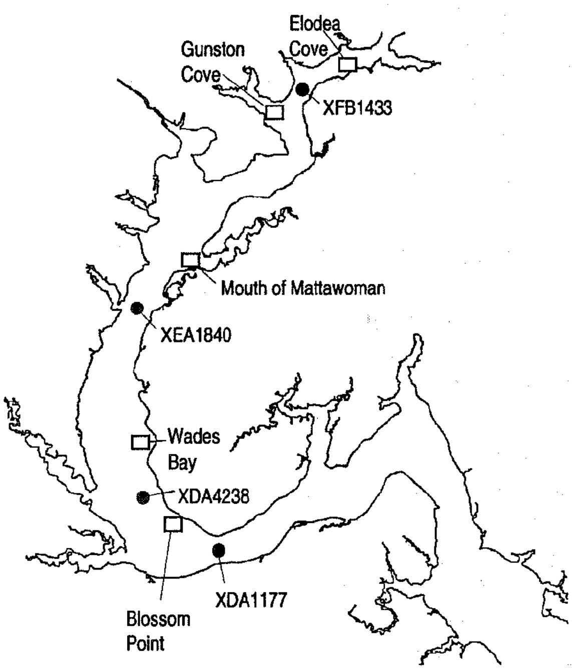


Figure VII-2. Upper Potomac River nearshore (□) and mid-channel (●) water quality monitoring stations used in the data analysis.

Choptank River Nearshore and Mid-channel Water Quality Monitoring Stations

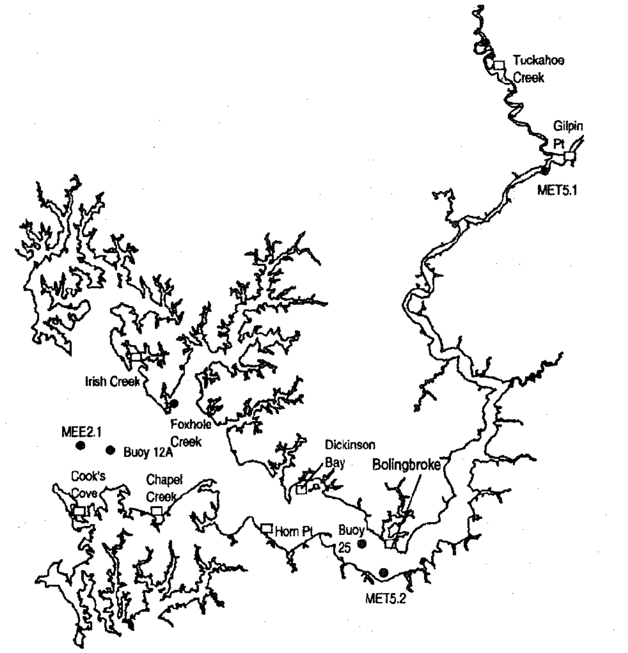


Figure VII-3. Choptank River nearshore (□) and mid-channel (●) water quality monitoring stations used in the data analysis.

Upper Bay Nearshore and Mid-channel Water Quality Monitoring Stations

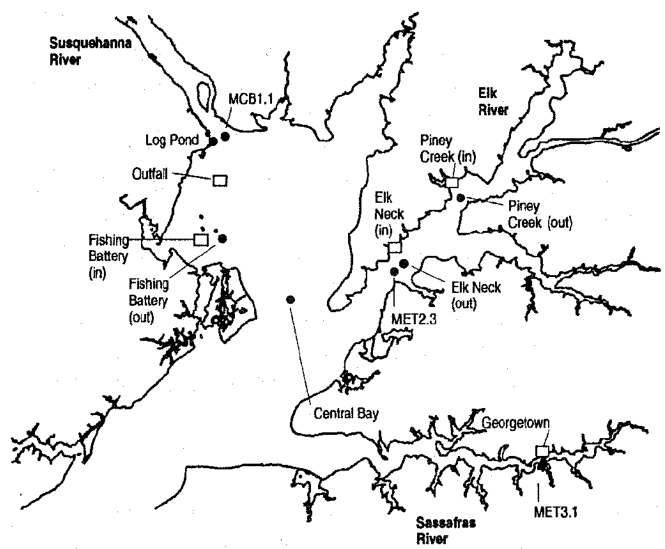


Figure VII-4. Upper Chesapeake Bay nearshore (□) and mid-channel (●) water quality monitoring stations used in the data analysis.

Upper Potomac River

Nine water quality monitoring stations, located in the upper Potomac River between the U.S. Route 301 bridge at Morgantown and Piscataway Creek, were chosen to compare nearshore and mid-channel water quality (Figure VII-2). Four of these stations were mid-channel stations monitored by the Maryland Department of the Environment (MDE) as part of the Chesapeake Bay Water Quality Monitoring Program. The other five stations, located in the nearshore, were monitored by the U.S. Geological Survey (USGS) in 1985 and 1986 as part of the USGS Wetland Studies Project.

The nearshore samples collected by USGS were taken at 0.33 m below the surface in less than 3 m of water depth outside SAV beds. MDE mid-channel samples were taken at 0.5 m depth from a boat in unvegetated areas of greater than 3 m depth. Table VII-2 presents the characteristics of each station. Salinities in this area ranged from oligohaline to tidal fresh and decreased with distance upstream. The sediments are silt-clay in the mid-channel, becoming sand-rich in shallow water.

Choptank River

Fourteen water quality monitoring stations, located between river kilometer 6 and river kilometer 82, were chosen for analysis in the Choptank River (Figure VII-3). Three mid-channel stations were monitored by MDE as part of the Chesapeake Bay Water Quality Monitoring Program. The remaining eleven stations, two mid-channel and nine nearshore, were monitored by the University of Maryland Horn Point Environmental Laboratory (HPEL) as part of their SAV transplanting research program.

The nearshore sites in the Choptank River were located along the margins of the river at water depths of 3 m or less and were sampled at a depth of 0.33 m. Nearshore stations in the lower part of the Choptank were in protected coves while those in the upper river were located in shallow areas adjacent to the mainstem of the river. The mid-channel stations were located along the axis of the river in water depths greater than 3 m and were sampled at a depth of 0.5 m. The HPEL stations were sampled monthly while the MDE stations were sampled twice a month.

Table VII-3 presents the characteristics of the water quality monitoring stations in the Choptank River. Due to the wide salinity and water quality gradients over which the Choptank River was sampled, stations were grouped into three general geographic areas for analysis–the Choptank embayment, the Cambridge area, and the Tuckahoe confluence area.

Upper Chesapeake Bay

Thirteen water quality monitoring stations, located in the Sassafras River, Elk River and Susquehanna Flats, were chosen for comparison in the upper portion of Chesapeake Bay (Figure VII-4). Nine of these stations, four mid-channel and five nearshore, were monitored monthly by Harford Community College (HCC) from April through October in 1988 and 1989 as part of an SAV transplanting program. The remaining three mid-channel stations were monitored by MDE as part of the Chesapeake Bay Water Quality Monitoring Program. Two of these stations, located in the Elk and Sassafras rivers, were monitored monthly. The other MDE mid-channel station, located in the mainstem of the Bay near the Susquehanna River, was monitored twice a month.

The nearshore stations in the upper Bay region were located along the margins of the Susquehanna Flats and the Sassafras and Elk rivers at water depths of less than 3 m. All of the nearshore samples were collected at a depth of 0.5 m adjacent to beds of SAV. All of the mid-channel samples were collected in water greater than 3 m deep at a depth of 0.5 m and away from any vegetation.

Salinities in this upper Bay region ranged from oligohaline to tidal fresh with most of the sampling stations located in tidal fresh areas. Sediments along the eastern shore of the Susquehanna Flats consisted of sand and pebbles in nearshore areas. These sediments became finer textured (i.e., silt and clay) moving toward the central area of the Susquehanna Flats. Station characteristics are presented in Table VII-4.

Methods

The following parameters were chosen for comparison between the nearshore and mid-channel stations: light attenuation coefficient, total suspended solids, chlorophyll *a*, dissolved inorganic nitrogen, and dissolved inorganic phosphorus. These parameters are consistent with those listed as SAV habitat requirements for one meter restoration. In the York River region, lack of adequate data for chlorophyll *a* prevented comparisons of that parameter.

Analytical methods for each parameter varied with the data sets measured. Summaries of the methods used by VIMS, HPEL, and HCC to collect and analyze data have been previously described in the case study sections. Method summaries for the data collected by the MDE, VWCB, and the USGS are provided in Appendix B.

Table VII-2. Characteristics of the upper Potomac River water quality monitoring stations.

Station	Years	Vegetated	Salinity
Blossom Point USGS nearshore; site location variable; mostly in vicinity of Maryland Point	1985	Yes	Oligohaline
XDA1177 (RET 2.2) MDE mid-channel site off Maryland Point	1984-1989	No	Oligohaline
XDA 4238 (RET 2.1) Mid-channel site off Smith Point	1984-1989	No	Oligohaline
Wades Bay USGS nearshore site; shoreline low profile and forested	1985-1986	Yes	Oligohaline
XEA1840 (TF2.4) MDE mid-channel site off mouth of Mattawoman Creek	1984-1989	No	Tidal Fresh
Mouth Mattawoman USGS nearshore site in mouth of Mattawoman Creek just outside first point (inside if very windy)	1985-1986	No	Tidal Fresh
Gunston Cove USGS nearshore site in mouth of Gunston Cove; well offshore near channel marker #64	1985-1986	Yes	Tidal Fresh
XFB1433 (TF2.2) MDE mid-channel site off mouth of Dogue Creek	1984-1989	No	Tidal Fresh
Elodea Cove USGS nearshore site; low profile shoreline; forested	1985-1986	Yes	Tidal Fresh

Secchi depths were converted to light attenuation coefficients (Kd) based upon linear relationships derived between Secchi depth and attenuation of photosynthetically active radiation. A relationship of Kd=1.38/Secchi depth was used for the Potomac River stations (Carter and Rybicki 1990) while Kd=1.45/Secchi depth was used for all other Secchi data (Moore, unpublished data).

Comparisons were made for a growing season of April to October in the Choptank and upper Bay areas. In the upper Chesapeake Bay, comparisons for all of the variables except light attenuation coefficient were restricted to 1989 due to analytical problems with the nearshore data. For the nearshore Potomac stations, data were available only from May through September of 1985 and April through August of 1986. Therefore, comparisons for the Potomac were confined to this time frame. A bi-modal growing season based upon ambient water temperature was used for comparisons in the York River. The seasons for this analysis were chosen to be consistent with the criteria used for application of the SAV habitat requirements.

Comparisons were made between pairs or groupings of nearshore and mid-channel stations which were considered to be in the same general region of the systems examined (Table VII-5). Data comparisons between the paired

Table VII-3. Characteristics of Choptank River nearshore and mid-channel water quality monitoring stations.

Station	Years	Vegetated	Salinity
MEE2.1 MDE mid-channel site in the Choptank River Embayment	1984-1990	No	Mesohaline
Buoy 12A HPEL mid-channel site in the Choptank River Embayment	1987-1989	No	Mesohaline
Cook's Cove HPEL nearshore site within Cook's Cove in the Choptank Embayment	1986-1989	Yes	Mesohaline
Chapel Creek HPEL nearshore site within a cove in the Choptank Embayment	1986-1989	Yes	Mesohaline
Irish Creek HPEL nearshore site within a cove in the Choptank Embayment	1986-1989	Yes	Mesohaline
Foxhole Creek HPEL nearshore site within a cove in the Choptank Embayment	1986-1989	Yes	Mesohaline
Horn Point HPEL nearshore site near Cambridge along the shore of the Choptank River	1986-1989	Yes	Mesohaline
Dickinson Bay HPEL nearshore site near Cambridge within a cove	1986-1989	Yes	Mesohaline
Buoy 25 HPEL mid-channel site near Cambridge	1987-1989	No	Mesohaline
MET5.2 MDE mid-channel site near Cambridge	1984-1989	No	Mesohaline
Bolingbroke HPEL nearshore site near Cambridge within a cove	1986-1989	Yes	Mesohaline
MET5.1 MDE mid-channel site near the confluence of Tuckahoe Creek	1984-1989	No	Tidal Fresh
Gilpin Point HPEL nearshore site along the shore near the Tuckahoe Creek confluence	1986-1989	No	Tidal Fresh
Tuckahoe Creek HPEL nearshore site along the shore of Tuckahoe Creek near the confluence	1986-1989	No	Tidal Fresh

Table VII-4. Characteristics of the upper Chesapeake Bay water quality monitoring stations.

Station	Years	Vegetated	Salinity
Log Pond HCC mid-channel site in the mouth of the Susquehanna River	1988-1989	No	Tidal Fresh
Outfall HCC nearshore site in the mouth of the Susquehanna River	1988-1989	No	Tidal Fresh
Fishing Battery (in) HCC nearshore site in the Susquehanna Flats of upper Chesapeake Bay	1988-1989	Yes	Tidal Fresh
Fishing Battery (out) HCC mid-channel site in the Susquehanna Flats of upper Chesapeake Bay	1988-1989	No	Tidal Fresh
Central Bay HCC mid-channel site in the central Susquehanna Flats	1988-1989	No	Tidal Fresh
MCB1.1 MDE mid-channel site near the outfall of the Susquehanna River	1984-1989	No	Tidal Fresh
Piney Creek (in) HCC nearshore site in Piney Creek along the Elk River	1988-1989	No	Tidal Fresh
Piney Creek (out) HCC mid-channel site in Piney Creek along the Elk River	1988-1989	No	Tidal Fresh
Elk Neck (in) HCC nearshore site in cove along the shore of the Elk River	1988-1989	Yes	Tidal Fresh
Elk Neck (out) HCC mid-channel site adjacent to Elk Neck (in)	1988-1989	No	Tidal Fresh
MET2.3 MDE mid-channel site adjacent to Elk Neck	1984-1989	No	Tidal Fresh
Georgetown HCC nearshore site along the shore of the Sassafras River near Georgetown	1988-1989	No	Tidal Fresh
MET3.1 MDE mid-channel site adjacent to HCC nearshore site Georgetown	1984-1989	No	Tidal Fresh

Table VII-5. Groupings of stations for nearshore/mid-channel comparison analysis with the mid-channel stations underlined.

Stations	Groups
York Stations	
Guinea Marsh	Group 1
WE 4.2	
Gloucester Point	Group 2
LE4.3	
Claybank	Group 3
LE4.2	
Potomac Stations	
Blossom Point	Group 1
XDA1177	
Wades Bay	Group 2
XDA4238	
Mouth Mattawoman	Group 3
XEA1840	
Gunston Cove	Group 4
XFB1433	
Elodea Cove	Group 4—both nearshore sites
XFB1433	compared to XFB1433.
Choptank Stations	
MEE2.1.	Group 1—Choptank embayment/pairwise
Buoy 12A	comparisons made between all stations.
Irish Creek	
Chapel Creek	
Cook's Cove	
Foxhole Creek	
MET5.2.	Group 2—Cambridge area/pairwise comparisons
Buoy 25	made between all stations.
Horn Point	
Dickinson Bay	
Bolingbroke Creek	
MET5.1.	Group 3—Tuckahoe confluence.
Gilpin Point	
Tuckahoe Creek	
Upper Bay Stations	
Log Pond	Group 1—Susquehanna Flats/pairwise
Outfall	comparisons made between all stations.
Fishing Battery (in)	
Fishing Battery (out)	
Central Bay	
MCB1.1	
Piney Creek (in)	Group 2—Elk River.
Piney Creek (out)	
Elk Neck (in)	Group 3—Lower Elk River/comparisons
Elk Neck (out)	between all stations.
MET2.3	
Georgetown	Group 4—Sassafras River.
MET3.1	

Surface Temperatures in the York River - Guinea Marsh and WE4.2 -

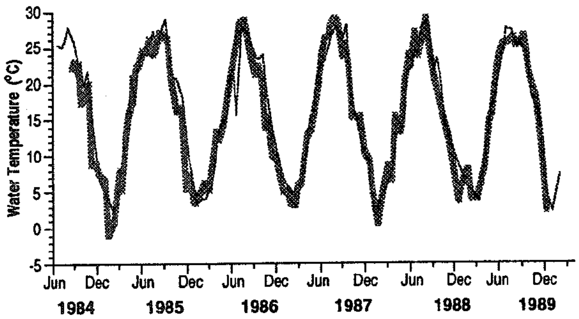


Figure VII-5. Comparison of nearshore (Guinea Marsh ▬) and mid-channel (WE4.2 —) water column surface temperatures in the York River from 1984-1989.

Surface Temperatures in the York River - Gloucester Point and LE4.3 -

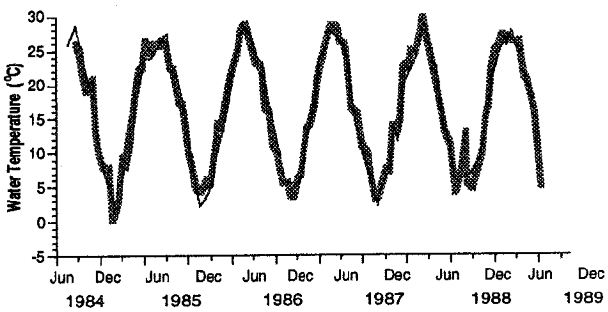


Figure VII-6. Comparison of nearshore (Gloucester Point ▬) and mid-channel (LE4.3 —) water column surface temperatures in the York River from 1984-1989.

Surface Temperatures in the York River - Claybank and LE4.2 -

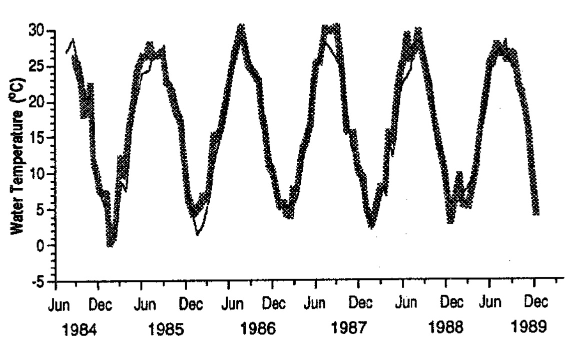


Figure VII-7. Comparison of nearshore (Claybank ▬) and mid-channel (LE4.2 —) water column surface temperatures in the York River from 1984-1989.

stations were explored using descriptive statistics, histograms, and time series plots of all available data. Formal statistical comparisons between paired stations for each of the investigated variables were made using SPSSX (SPSS, Inc.) statistical software with the York River data and SAS (SAS Institute, 1985) for all other areas. In each case, a distribution free rank sum test (Wilcoxon/Mann-Whitney U) was used to test if the distributions of the two-paired sample populations for each variable were the same (Daniel 1987, Hipel and McLeod 1990, SAS 1985). All comparisons were made on a year-by-year basis to factor out interannual changes in water quality. In the York River, an annual period consisting of the spring, summer, and fall (roughly April to October) was chosen to provide a comparable time frame to the year-by-year analyses of the lower salinity regions. In addition, for this region individual seasons were also analyzed using 1985-1988 data.

Different methods and sampling schedules employed by the various monitoring agencies were identified as factors with the potential to have an effect on the results of this study. Extensive data comparisons, method evaluations, and quality assurance checks were employed to minimize the effects of differing methods. One consequence of using different analytical methods was widely differing detection limits for some of the investigated water quality variables. In cases where >50% of the measurements for a variable at a station were below the detection limit for that variable, no comparison was made. The effect of different sampling schedules on the outcomes of the statistical tests was unknown but likely to increase variability. It is important to note that many of the nearshore sites were located within coves or somewhat up or down the estuary from neighboring mid-channel sites. These spatial factors contributed to the observed variability due to localized nearshore influences or longitudinal gradients in some water quality variables.

Results

York River

Water Temperature

Water temperatures were quite similar between stations (Figures VII-5, VII-6, and VII-7) with no evidence of significant differences between nearshore and mid-channel stations (one exception was Claybank/LE4.2 for summer). No significant differences were observed at other sites when stations were compared on a seasonal (Table VII-6) or annual (Table VII-7) basis.

Table VII-6. Statistical comparison of nearshore/mid-channel station data for individual seasons in the York River 1985-1988.

Stations	Season	Temp.	Sal.	Kd	TSS	DIN	DIP
Guinea Marsh/ WE4.2	Winter	NS	NS	NS	NS	NS	**
	Spring	NS	NS	NS	NS	**	**
	Summer	NS	NS	NS	NS	**	**
	Fall	NS	NS	NS	NS	p=.02	NS
Gloucester Point/ LE4.3	Winter	NS	p=.0001	NS	NS	**	**
	Spring	NS	NS	NS	NS	**	**
	Summer	NS	p=.008	p=.0001	p=.008	**	p=.001
	Fall	NS	p=.001	NS	NS	**	NS
Claybank/ LE4.2	Winter	NS	p=.0001	NS	ND	**	**
	Spring	NS	p=.01	NS	ND	**	**
	Summer	p=.04	p=.001	NS	ND	**	p=.0001
	Fall	NS	p=.001	NS	ND	NS	NS

NS = not significant (p>.05)
ND = no available data
** = not comparable due to detection limit

Table VII-7. Statistical comparisons of nearshore/mid-channel station data by years for the York River 1985-1988.

Stations	Year	Temp.	Sal.	Kd	TSS	DIN	DIP
Guinea Marsh/ WE4.2	1985	NS	NS	NS	NS	**	**
	1986	NS	NS	NS	NS	**	**
	1987	NS	NS	NS	p=.02	p=.048	**
	1988	NS	NS	NS	p=.05	p=.009	p=.0001
Gloucester Point/ LE4.3	1985	NS	p=.0001	p=.002	p=.002	**	**
	1986	NS	NS	NS	p=.02	**	**
	1987	NS	NS	NS	**	**	**
	1988	NS	NS	NS	NS	**	**
Claybank/ LE4.2	1985	NS	p=.0001	p=.002	ND	**	**
	1986	NS	p=.02	NS	ND	**	**
	1987	NS	NS	NS	ND	**	**
	1988	NS	NS	NS	NS	**	**

NS = not significant (p>.05)
ND = no available data
** = not comparable due to detection limit

Surface Salinities in the York River
- Guinea Marsh and WE4.2 -

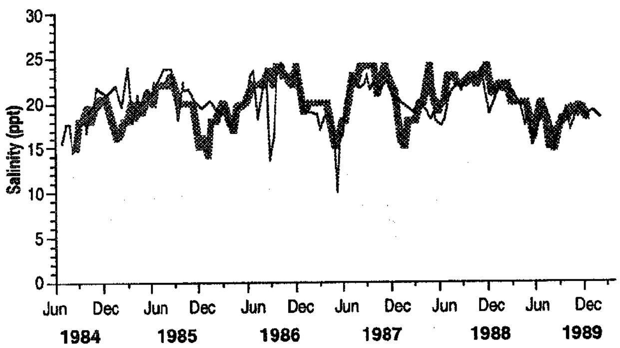


Figure VII-8. Comparison of nearshore (Guinea Marsh ▬) and mid-channel (WE4.2 —) water column surface salinities in the York River from 1984-1989.

Surface Salinities in the York River
- Gloucester Point and LE4.3 -

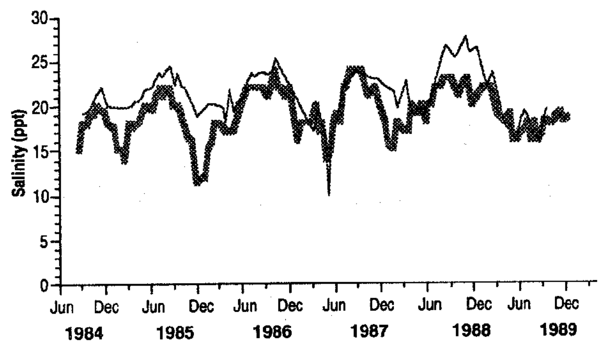


Figure VII-9. Comparison of nearshore (Gloucester Point ▬) and mid-channel (LE4.3 —) water column surface salinities in the York River from 1984-1989.

Surface Salinities in the York River
- Claybank and LE4.2 -

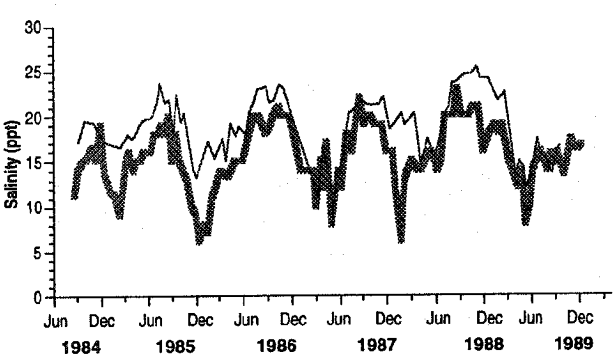


Figure VII-10. Comparison of nearshore (Claybank ▬) and mid-channel (LE4.2 —) water column surface salinities in the York River from 1984-1989.

<u>Salinity</u>

Salinities at the Guinea Marsh and WE4.2 stations displayed similar variability (Figure VII-8) when compared on a seasonal or annual basis (Tables VII-6 and VII-7). At the upriver Gloucester Point and LE4.3 stations, salinities were slightly lower at the nearshore station during the winter, summer, and fall (Figure VII-9). When compared by year, significant differences were evident only during 1985 (Tables VII-6 and VII-7). This may be due to the slightly upriver location of the nearshore stations. At Claybank (Figure VII-10), salinities were significantly lower than LE4.2 during all seasons and during 1985 through 1986 (Tables VII-6 and VII-7). This difference in salinity may affect the comparison of other water quality variables between these two sites.

<u>Light Attenuation Coefficient</u>

Increasing light attenuation coefficient levels were observed during spring and summer (Figure VII-11) at both Guinea Marsh and WE4.2. Although more variable and occasionally higher levels were found in the nearshore, when compared over seasonal and annual periods (Tables VII-6 and VII-7), no significant differences were found. At Gloucester Point and LE4.3, significantly higher levels occurred at the nearshore site during the summer (Figure VII-12 and Table VII-6), but only 1985 was significantly different when compared over the annual growing season (Table VII-7). Seasonally, light attenuation coefficients were highest during the spring and early summer at Claybank and LE4.2, with lowest levels during the winter (Figure VII-13). One significant difference was detected between the locations in 1985 (Tables VII-6 and VII-7).

<u>Total Suspended Solids</u>

Total suspended solids at WE4.2 showed greater variability over time when compared to Guinea Marsh (Figure VII-14). Although levels might be expected to be higher in the nearshore due to local resuspension by wave action, no significant differences were observed between sites when compared on a seasonal basis (Table VII-6). However, differences were significant for 1987 and 1988 when compared annually (Table VII-7).

At Gloucester Point and LE4.3 (Figure VII-15), seasonally determined medians were significantly different only during the summer. Limited data during the summer of 1987 at LE4.3 prevented comparison during that period. On an annual basis, the nearshore site was significantly higher during 1985 and 1986 (Table VII-7). During 1988, three very high values at LE4.3 were in contrast to the pattern of higher levels of total suspended solids in the nearshore. A detection limit, which varied from 3 to 6 mg/l for the LE4.3 site, also biased the data toward higher levels in the mid-channel. During the period between September 1984 and June 1987, approximately 12 of the 32 records at LE4.3 were at the detection limit.

Total suspended solid concentrations were higher at the Claybank site (Figure VII-16) compared to the downriver nearshore stations. Seasonal concentrations were highest during the summer period. A lack of total suspended solids data at LE4.2 prior to June 1987 prevented comparison with Claybank, except during 1988 when no statistically significant difference between the stations was observed.

Dissolved Inorganic Nitrogen

Significantly higher levels of dissolved inorganic nitrogen were observed during the fall at WE4.2 compared to the nearshore Guinea Marsh site (Table VII-6). Although in many years dissolved inorganic nitrogen levels in the mid-channel were higher than nearshore during the winter, the differences were not significant when data were compared over the four years. Detection limits were too high during much of the 1984-1986 period at the mid-channel station WE4.2 (Figure VII-17) to compare with the adjacent near-shore station. However, during 1987 and 1988, growing seasons levels were significantly greater at the mid-channel station than the nearshore station (Table VII-7).

At LE4.3, the high detection limits for the Virginia tributary monitoring data made this data set a poor record of nitrogen concentrations in this region of the York River (Figure VII-18). Except during a short period in the fall and winter, levels of dissolved inorganic nitrogen were at or below detection. Therefore, no comparisons could be made between Gloucester Point and LE4.3 (Tables VII-6 and VII-7). Maximum levels of dissolved inorganic nitrogen were reported lower at the mid-channel station LE4.3 than downriver at WE4.2. This was in contrast to the nearshore stations Guinea Marsh (Figure VII-17) and Gloucester Point (Figure VII-18) where the pattern was one of increasing concentrations with distance upriver.

At Claybank and LE4.2, a high number of data at the detection limit for dissolved inorganic nitrogen were evident at the mid-channel site (Figure VII-19). Therefore, only one direct statistical comparisons could be made between the two sites in the fall.

Comparisons for the York River region demonstrated problems associated with detection limits in the polyhaline and mesohaline portions of the western tributaries. Dis-

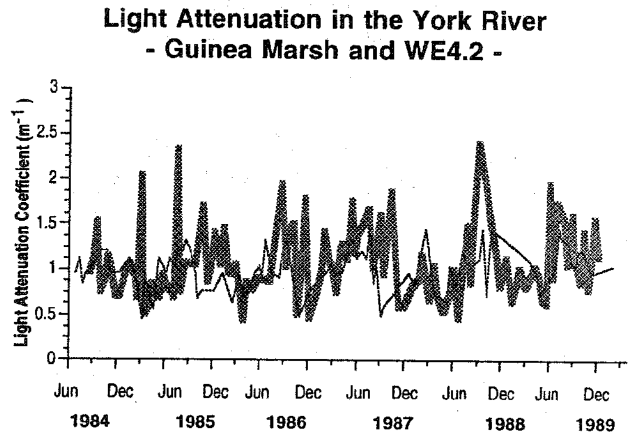


Figure VII-11. Comparison of nearshore (Guinea Marsh ▬) and mid-channel (WE4.2 —) light attenuation coefficients in the York River from 1984-1989.

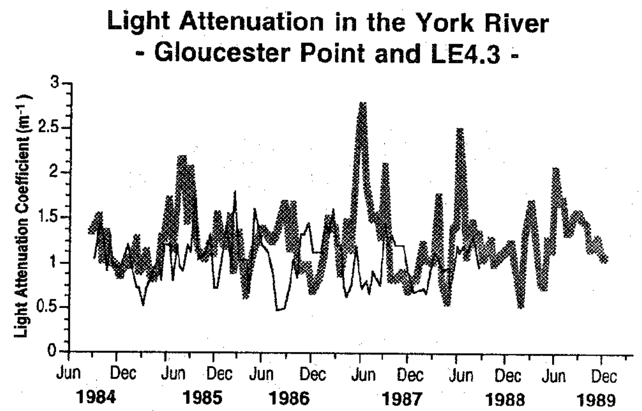


Figure VII-12. Comparison of nearshore (Gloucester Point ▬) and mid-channel (LE4.3 —) light attenuation coefficients in the York River from 1984-1989.

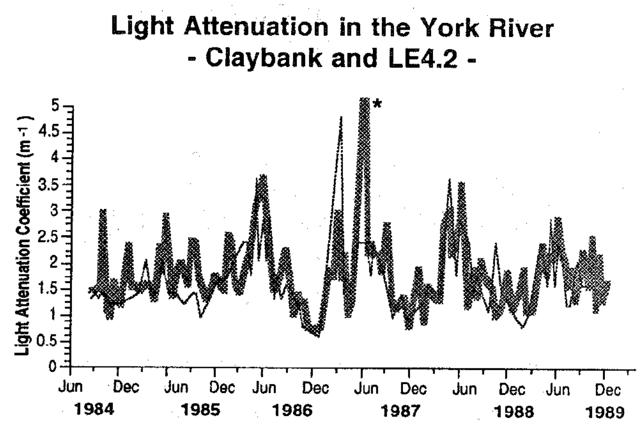


Figure VII-13. Comparison of nearshore (Claybank ▬) and mid-channel (LE4.2 —) light attenuation coefficients in the York River from 1984-1989 (*June 1987 Claybank light attenuation coefficient measurement was 7.0 m^{-1}).

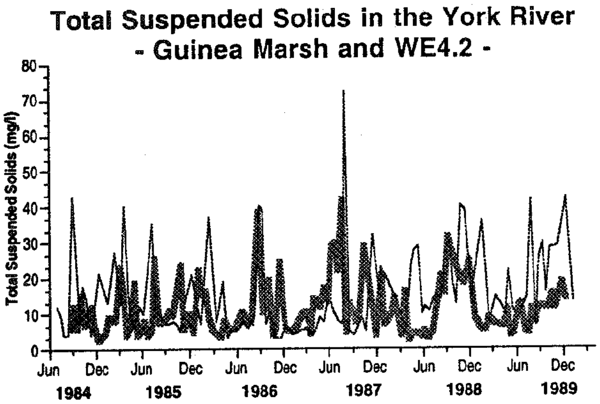


Figure VII-14. Comparison of nearshore (Guinea Marsh ▬) and mid-channel (WE4.2 —) surface total suspended solids concentrations in the York River from 1984-1989.

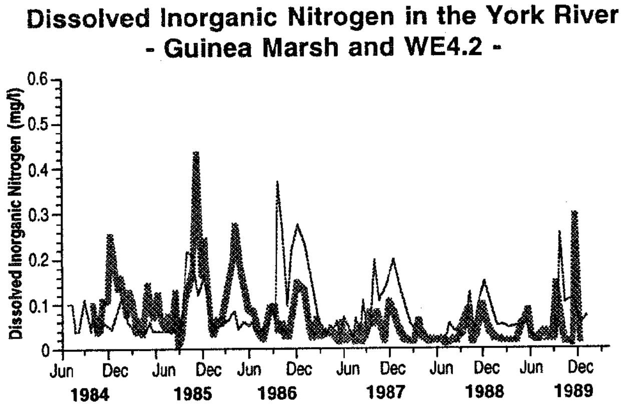


Figure VII-17. Comparison of nearshore (Guinea Marsh ▬) and mid-channel (WE4.2 —) surface dissolved inorganic nitrogen concentrations in the York River from 1984-1989.

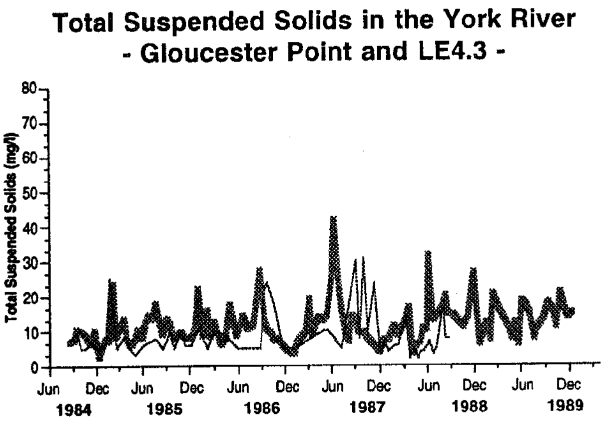


Figure VII-15. Comparison of nearshore (Gloucester Point ▬) and mid-channel (LE4.3 —) surface total suspended solids concentrations in the York River from 1984-1989.

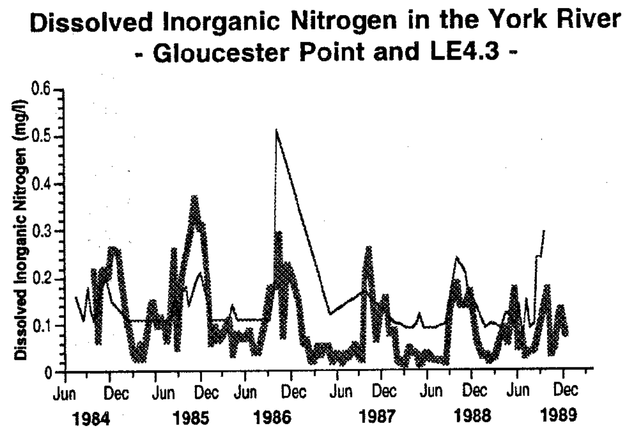


Figure VII-18. Comparison of nearshore (Gloucester Point ▬) and mid-channel (LE4.3 —) surface dissolved inorganic nitrogen concentrations in the York River from 1984-1989.

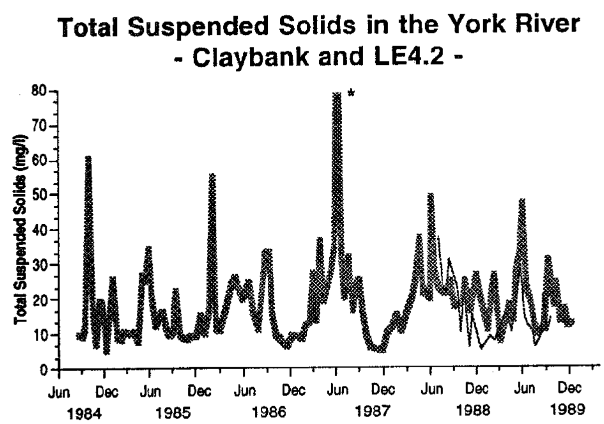


Figure VII-16. Comparison of nearshore (Claybank ▬) and mid-channel (LE4.2 —) surface total suspended solids concentrations in the York River from 1984-1989 (*June 1987 Claybank total suspended solids concentration was 107 mg/l).

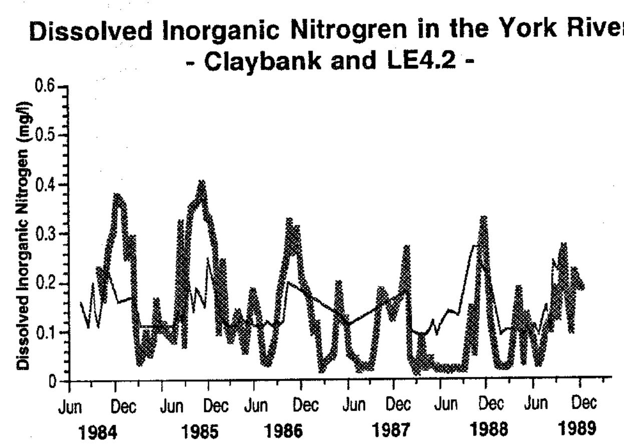


Figure VII-19. Comparison of nearshore (Claybank ▬) and mid-channel (LE4.2 —) surface dissolved inorganic nitrogen concentrations in the York River from 1984-1989.

solved inorganic nitrogen levels characteristic of these regions during the warmer months were often below the detection limits of the mid-channel monitoring program in the York River. Therefore, the mid-channel data was unsuitable for comparison to nearshore water quality.

Dissolved Inorganic Phosphorus

Dissolved inorganic phoshorus comparisons generally show increasing divergence between mid-channel and nearshore measurements with distance upriver as the absolute levels of dissolved inorganic phosphorus increase (Figures VII-20, VII-21, and VII-22). High detection limits at the mid-channel monitoring stations, however, relative to the absolute concentrations present in the river, obscured the statistical quantification of this trend. For examle, mid-channel data for the Guinea Marsh and WE4.2 comparison were at the detection limit for much of the time between 1984 and 1987 (Figure VII-20) and no direct growing season comparisons could be made. Changes in analytical methodology at the end of 1987 for this mid-channel station (WE4.2) resulted in lower detection limits. These lower limits resulted in significantly smaller reported mid-channel levels of dissolved inorganic phosphorus compared to the nearshore site for the 1988 growing season (Table VII-7). During the fall of each year, the levels at this mid-channel station were above the detection limit (Figure Vii-20), permitting statistical analysis; no significant difference between the midchannel and nearshore stations were found.

At the two upriver mid-channel stations (LE4.3 and LE4.2), high detection limits obscured comparisons with the nearshore data (Figures VII-21 and VII-22), except from June through December each year. Similar patterns of increasing levels during the fall and early winter are evident at both nearshore and mid-channel sites, as are generally increasing levels at each site with distance upriver. The levels were not significantly different between the respective nearshore and mid-channel stations during the fall, but were significantly different during the summer (Table VII-6). Because of the high detection limits at these two mid-channel stations, growing season means could not be statistically compared (Table VII-7), however concentrations appear higher at the nearshore stations, especially from December through June (Figures VII-21 and VII-22).

Upper Potomac River

Water Temperature

Surface water temperatures were not available for the nearshore areas of the Potomac, therefore, no comparisons could be made.

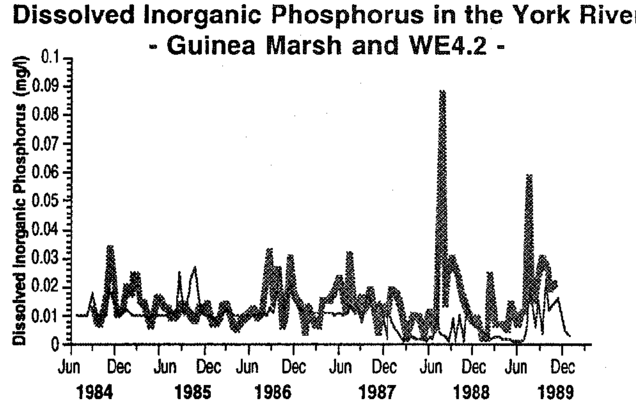


Figure VII-20. Comparisons of nearshore (Guinea Marsh ▬) and mid-channel (WE4.2 —) surface dissolved inorganic phosphorus concentrations in the York River from 1984-1989.

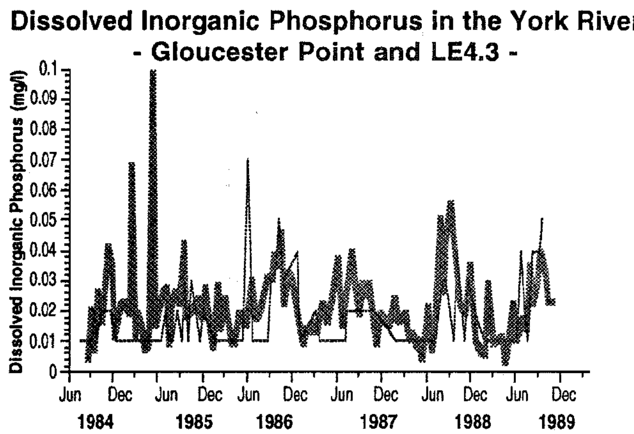


Figure VII-21. Comparisons of nearshore (Gloucester Point ▬) and mid-channel (LE4.3 —) surface dissolved inorganic phosphorus concentrations in the York River from 1984-1989.

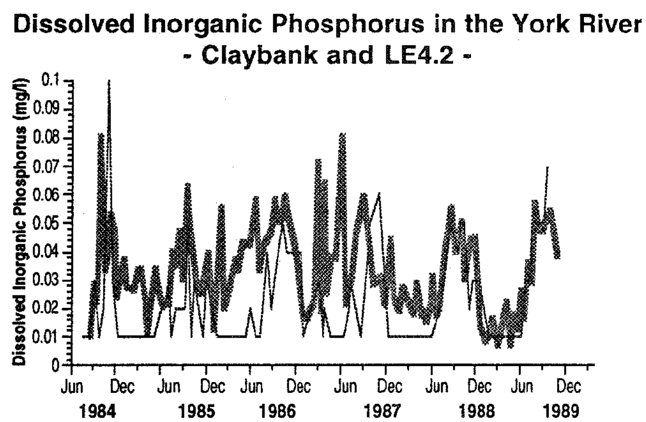


Figure VII-22. Comparisons of nearshore (Claybank ▬) and mid-channel (LE4.2 —) surface dissolved inorganic phosphorus concentrations in the York River from 1984-1989.

Table VII-8. Statistical comparisons of nearshore/mid-channel stations growing season medians in the upper Potomac River.

Stations	Year	KD	TSS	CHLA	DIN	DIP
Blossom Point/	1985	NS	NS	NS	NS	NS
XDA1177	1986	ND	ND	ND	ND	ND
Wades Bay/	1985	NS	NS	NS	ND	ND
XDA4238	1986	NS	NS	NS	ND	ND
Mouth Mattawoman/	1985	NS	NS	NS	NS	NS
XEA1840	1986	NS	p=.02	p<.0001	ND	ND
Gunston Cove/	1985	NS	NS	NS	NS	NS
XFB1433	1986	NS	p<.05	p<.006	ND	ND
Elodea Cove/	1985	NS	NS	NS	NS	NS
XFB1433	1986	p<.006	NS	p<.0035	ND	ND

NS = not significant (p<.05)
ND = no data available

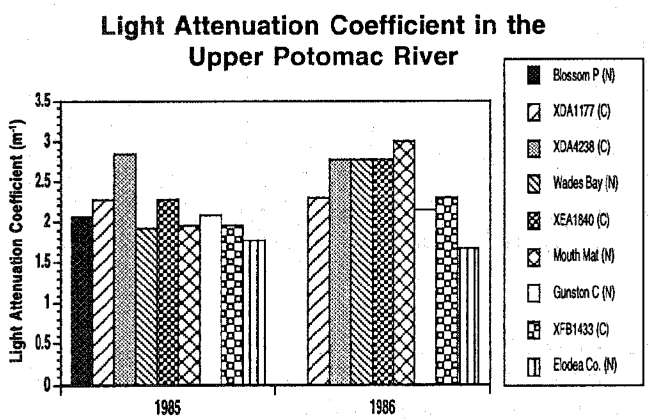


Figure VII-23. Comparisons of 1985 and 1986 growing season median light attenuation coefficients for nearshore (N) and mid-channel (C) monitoring stations in the upper Potomac River.

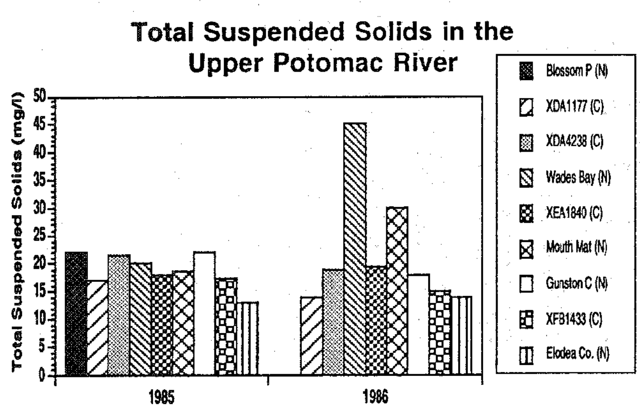


Figure VII-24. Comparisons of 1985 and 1986 growing season median total suspended solids concentrations for nearshore (N) and mid-channel (C) monitoring stations in the upper Potomac River.

Salinity

Surface salinities were not available for the nearshore areas of the Potomac. Based upon existing segmentation schemes and the geographical proximity of the nearshore/mid-channel station pairs, it was assumed that the salinities between nearshore/mid-channel station pairs were similar.

Light Attenuation Coefficient

In 1985, median growing season light attenuation coefficient levels demonstrated little variability between sites. Mid-channel sites, however, tended to have slightly higher light attenuation levels than adjacent nearshore sites (Figure VII-23). None of the observed differences was found to be significant (Table VII-8).

In 1986, median growing season light attenuation coefficient levels again exhibited only slight variability between sites (Figure VII-23). One mid-channel station, XFB1433, had statistically significant higher light attenuation coefficient levels than nearshore station Elodea Cove (Table VII-8). However, this same mid-channel station was also compared to a second neighboring nearshore station, (Gunston Cove) and the light attenuation coefficient levels at these two stations did not differ significantly. This result was somewhat surprising considering the extreme differences in chlorophyll *a* levels between these nearshore and mid-channel sites but was well supported by the total suspended solids values and exploratory graphical analyses for the Potomac River.

Total Suspended Solids

In 1985, a majority of the nearshore sites had median total suspended solid levels over the growing season that were similar to adjacent mid-channel sites (Figure VII-24). None of these comparisons were found to be statistically significant (Table VII-8).

In 1986, the nearshore sites generally exhibited higher median total suspended solids levels than adjacent mid-channel sites (Figure VII-24). Two nearshore stations, Mouth Mattawoman Creek and Gunston Cove, were found to have significantly greater levels of total suspended solids than the corresponding adjacent mid-channel sites (Table VII-8). In general, total suspended solids levels were more variable in 1986 than 1985. Some of these differences may have been caused in part by large phytoplankton blooms that are characteristic of certain coves in the Potomac River or by resuspension of sediments due to wave action.

Chlorophyll *a*

The nearshore sites (Mouth Mattawoman, Gunston Cove, and Elodea Cove), which are known to experience severe phytoplankton blooms, exhibited high levels of chlorophyll *a* in 1985 when compared to all other stations in the upper Potomac River (Figure VII-25). However, these differences were not found to be statistically significant (Table VII-8) and little variability was apparent between the other stations.

In 1986, chlorophyll *a* levels were significantly higher at the Mattawoman, Gunston Cove, and Elodea Cove sites compared to corresponding adjacent mid-channel sites (Table VII-8 and Figure VII-25). Chlorophyll *a* levels at these three nearshore sites were generally observed to be slightly higher in 1986 than in 1985–a year when no significant differences were found. The other nearshore station in the Potomac River (Wades Bay) was comparable to adjacent mid-channel stations in 1986 (Table VII-8 and Figure VII-25).

Dissolved Inorganic Nitrogen

Comparisons for dissolved inorganic nitrogen could only be made for 1985 due to a lack of data at the nearshore sites (Figure VII-26). In that year, no statistically significant differences were found for dissolved inorganic nitrogen between the nearshore and mid-channel areas that were compared (Table VII-8). Exploratory graphical analyses supported this finding that the nearshore and mid-channel levels of dissolved inorganic nitrogen in the Potomac were

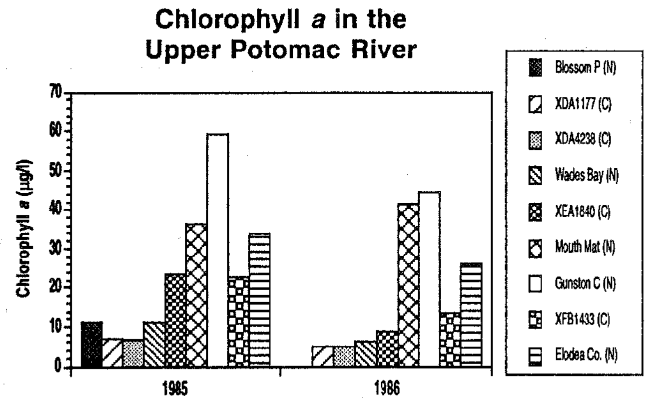


Figure VII-25. Comparisons of 1985 and 1986 growing season median chlorophyll *a* concentrations at nearshore (N) and mid-channel (C) monitoring stations in the upper Potomac River.

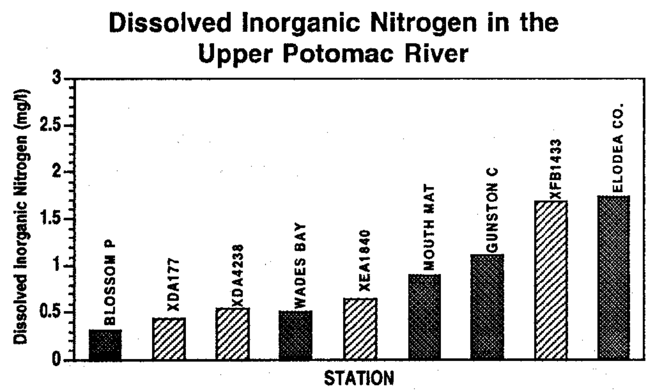


Figure VII-26. Comparison of 1985 growing season median dissolved inorganic nitrogen concentrations at nearshore (■) and mid-channel (▨) monitoring stations in the upper Potomac River.

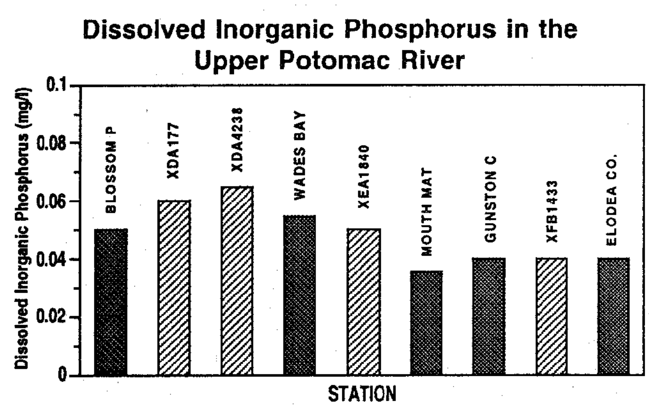


Figure VII-27. Comparisons of 1985 growing season median dissolved inorganic phosphorus concentrations for nearshore (■) and mid-channel (▨) monitoring stations in the upper Potomac River.

comparable. Some slight differences did exist in dissolved inorganic nitrogen levels between the stations, but these were most likely due to the longitudinal water quality gradient in the upper Potomac River (Figure VII-26).

Dissolved Inorganic Phosphorus

Comparisons for dissolved inorganic phosphorus could only be made for 1985 due to a lack of data at the nearshore sites. Analysis of this data indicated that levels of dissolved inorganic phosphorus were very similar in adjacent nearshore/mid-channel areas (Figure VII-27). No statistically significant differences were found for dissolved inorganic phosphorus between the nearshore and mid-channel areas that were compared (Table VII-8). Exploratory graphical analyses supported the finding that nearshore and mid-channel dissolved inorganic phosphorus levels in the upper Potomac River were comparable. Some slight differences did exist in dissolved inorganic phosphorus levels, but these were most likely due to the longitudinal water quality gradient in the upper Potomac River.

Choptank River

Water Temperature

Surface water temperatures were found to be nearly identical at adjacent nearshore and mid-channel stations, with some variability most likely due to different sampling times.

Salinity

Surface salinities were found to be nearly identical at adjacent nearshore and mid-channel stations, with some variability most likely due to different sampling times.

Light Attenuation Coefficient

In the Choptank River embayment, little variation in light attenuation coefficient levels was apparent among all the stations in all years (Figures VII-28 and VII-29). No significant differences were detected between the nearshore and mid-channel sites (Table VII-9).

In the Cambridge area, light attenuation coefficients were similar between the nearshore and mid-channel sites although the nearshore sites, Dickinson Bay and Bolingbroke Creek, generally had the highest levels (Figure VII-30). The elevated light attenuation coefficient levels at these two sites, which were often significantly greater than the light attenuation coefficient levels at other sites in the area

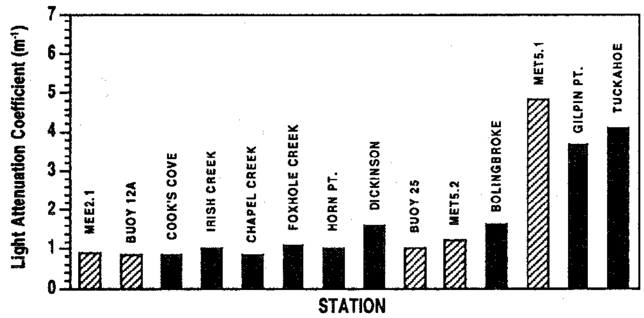


Figure VII-28. Comparisons of 1986-1989 growing season median light attenuation coefficients for the nearshore (■) and mid-channel (▨) monitoring stations in the Choptank River. This figure displays the longitudinal light attenuation coefficient gradient present in the Choptank River.

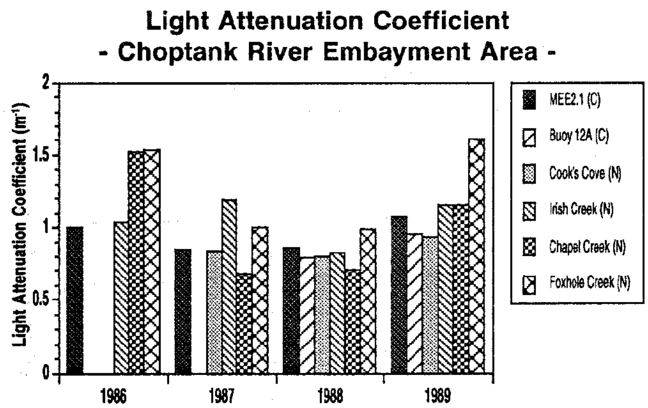


Figure VII-29. Comparisons of 1986-1989 growing season median light attenuation coefficients for nearshore (N) and mid-channel (C) monitoring stations in the Choptank River Embayment Area.

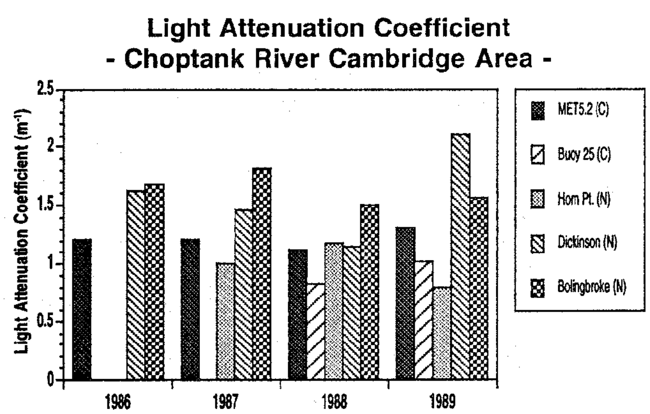


Figure VII-30. Comparisons of 1986-1989 growing season median light attenuation coefficients for nearshore (N) and mid-channel (C) monitoring stations in the Choptank River Cambridge Area.

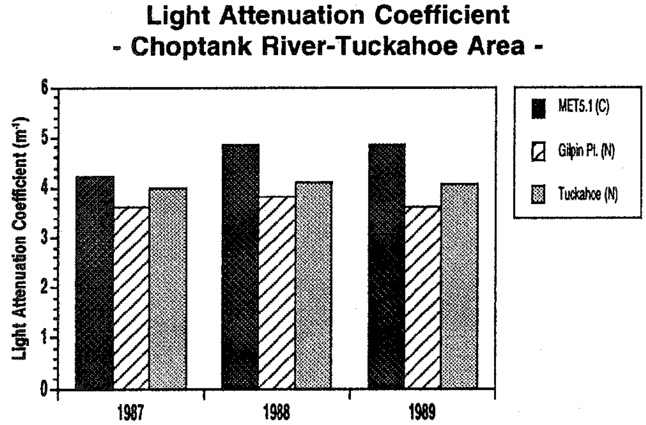


Figure VII-31. Comparisons of 1987-1989 growing season median light attenuation coefficients for nearshore (N) and mid-channel (C) monitoring stations in the Choptank River Tuckahoe Area.

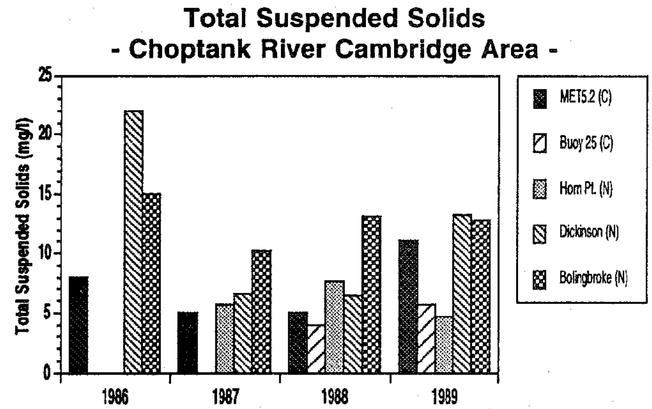


Figure VII-34. Comparisons of 1986-1989 growing season median total suspended solids concentrations for nearshore (N) and mid-channel (C) monitoring stations in the Choptank River Cambridge Area.

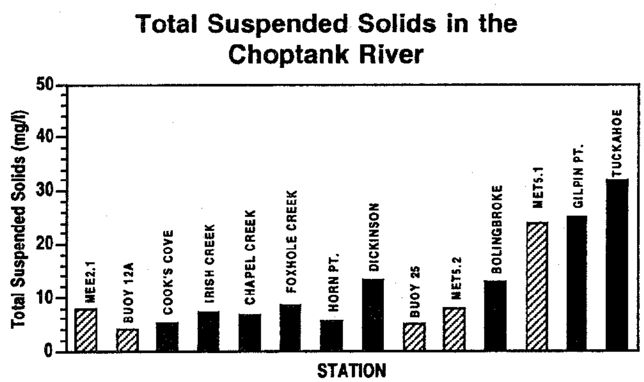


Figure VII-32. Comparisons of 1986-1989 growing season median total suspended solids concentrations for nearshore (■) and mid-channel (▨) monitoring stations in the Choptank River. This figure displays the longitudinal total suspended solids gradient present in the Choptank River.

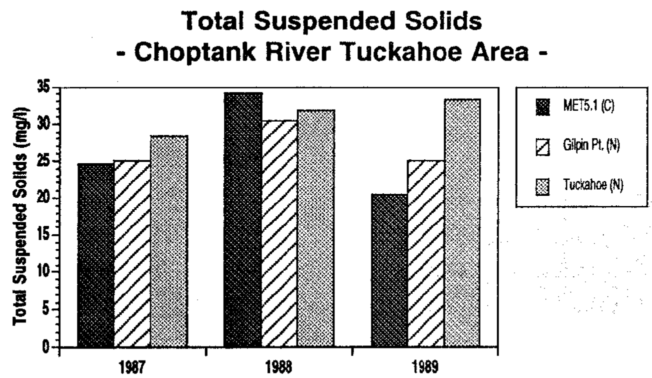


Figure VII-35. Comparisons of 1987-1989 growing season median total suspended solids concentrations for nearshore (N) and mid-channel (C) monitoring stations in the Choptank River Tuckahoe Area.

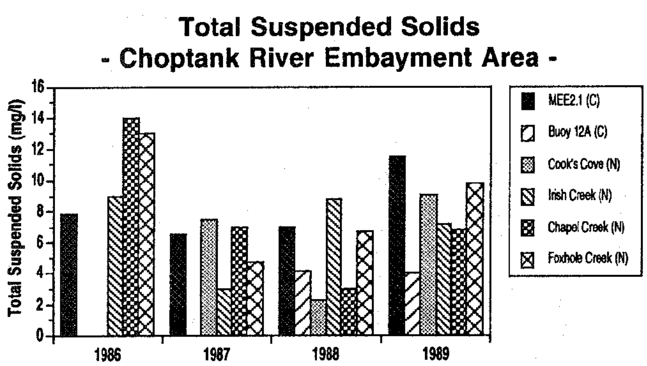


Figure VII-33. Comparisons of 1986-1989 growing season median total suspended solids concentrations for nearshore (N) and mid-channel (C) monitoring stations in the Choptank River Embayment Area.

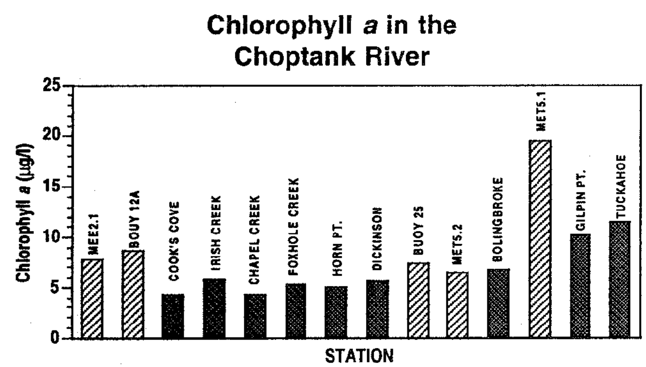


Figure VII-36. Comparisons of 1986-1989 growing season median chlorophyll *a* concentrations for nearshore (■) and mid-channel (▨) monitoring stations in the Choptank River.

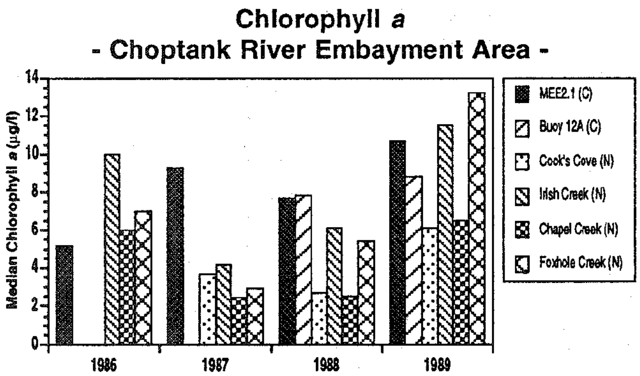


Figure VII-37. Comparisons of 1986-1989 growing season median chlorophyll *a* concentrations for nearshore (N)and mid-channel (C) monitoring stations in the Choptank River Embayment Area.

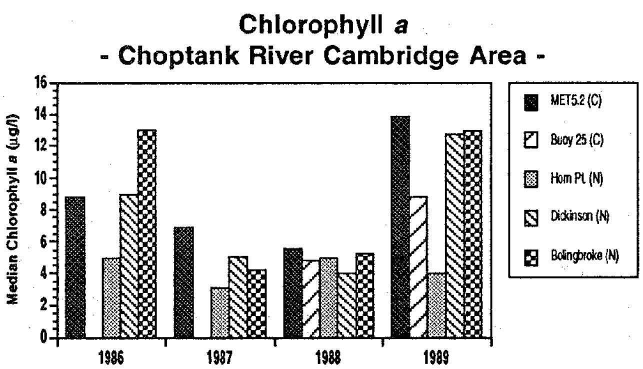


Figure VII-38. Comparisons of 1986-1989 growing season median chlorophyll *a* concentrations for nearshore (N) and mid-channel (C) monitoring stations in the Choptank River Cambridge Area.

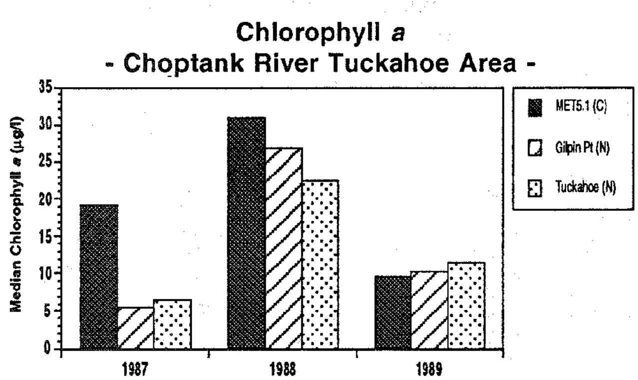


Figure VII-39. Comparisons of 1987-1989 growing season median chlorophyll *a* concentrations for nearshore (N) and mid-channel (C) monitoring stations in the Choptank River Tuckahoe Area.

(Table VII-10), were most likely related to the high total suspended solids levels that were also found at these two sites. Variability between the other stations in the area was minimal.

In the Tuckahoe area, little variation was detected in light attenuation coefficients between the nearshore and mid-channel sites (Figure VII-31). In general, however, median light attenuation coefficient levels were found to be slightly higher at the mid-channel site. One significant difference between mid-channel site MET5.1 and nearshore site Gilpin Point was detected in 1989 (Table VII-11).

Total Suspended Solids

In the Choptank River embayment area, total suspended solids concentrations were quite variable between stations and between years, but no consistent pattern was apparent between the nearshore and mid-channel areas (Figures VII-32 and VII-33). MDE mid-channel station MEE2.1 was found to have significantly greater total suspended solids levels than HPEL mid-channel station Buoy 12A, possibly indicating that the different sampling schedules and methods were biasing the results of these comparisons. However, few significant differences existed between the mid-channel and nearshore stations during the comparison period (Table VII-12). Variation among nearshore sites in the embayment was comparable to the variation between the nearshore and mid-channel sites.

In the Cambridge area of the Choptank River, nearshore sites Dickinson Bay and Bolingbroke Creek exhibited elevated total suspended solids levels in all years when compared to all other stations in this area (Figures VII-32 and VII-34). Several of these differences were found to be significant (Table VII-13). Total suspended solids levels between the other stations in this area were generally found to be comparable with little variability.

In the Tuckahoe area of the Choptank, total suspended solids levels showed little variation between the mid-channel and nearshore sites (Figures VII-32 and VII-35). Only one statistically significant difference, between mid-channel station MET5.1 and nearshore station Tuckahoe Creek, was detected (Table VII-14).

Chlorophyll *a*

The 1986 chlorophyll *a* levels in the embayment area were generally (but not significantly) lower in the mid-channel relative to the nearshore (Figures VII-36 and VII-37, and Table VII-15). In 1987 and 1988, the reverse was observed

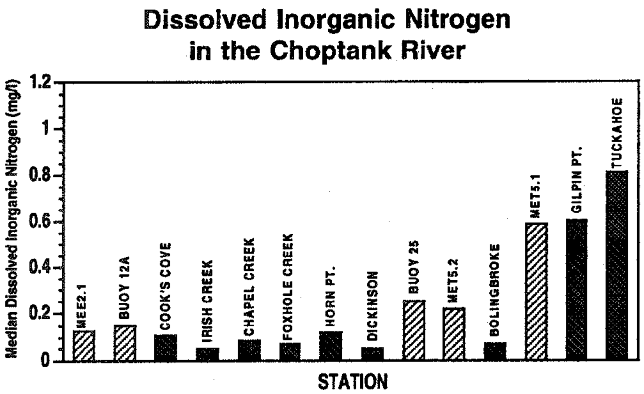


Figure VII-40. Comparisons of 1986-1989 growing season median dissolved inorganic nitrogen concentrations for the nearshore (■) and mid-channel (▨) monitoring stations in the Choptank River. This figure displays the longitudinal dissolved inorganic nitrogen gradient present in the Choptank River.

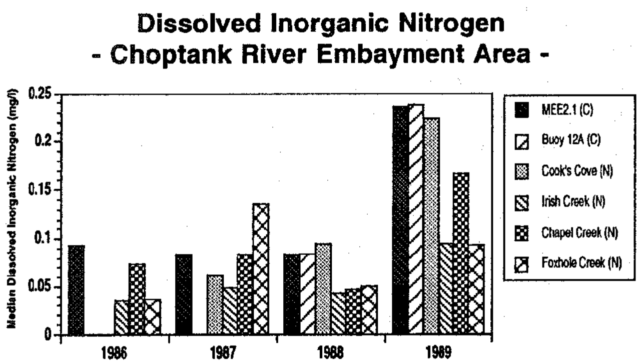


Figure VII-41. Comparisons of 1986-1989 growing season median dissolved inorganic nitrogen concentrations at nearshore (N) and mid-channel (C) monitoring stations in the Choptank River Embayment Area.

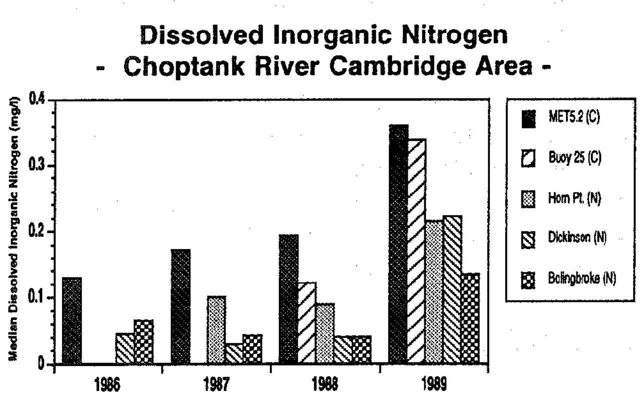


Figure VII-42. Comparison of 1986-1989 growing season median dissolved inorganic nitrogen concentrations at nearshore (N) and mid-channel (C) stations in the Choptank River Cambridge Area.

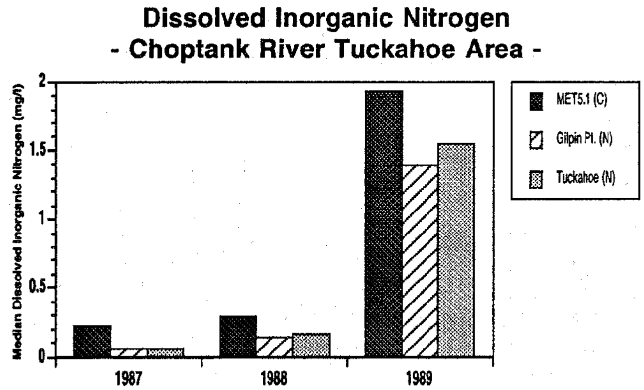


Figure VII-43. Comparison of 1987-1989 growing season median dissolved inorganic nitrogen concentrations for the nearshore (N) and mid-channel (C) monitoring stations in the Choptank River Tuckahoe Area.

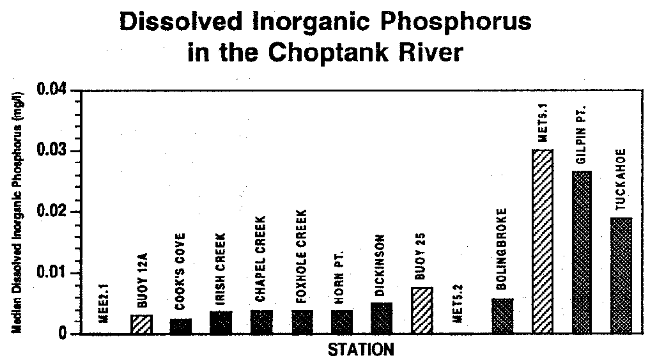


Figure VII-44. Comparisons of 1986-1989 growing season median dissolved inorganic phosphorus concentrations for the nearshore (■) and mid-channel (▨) monitoring stations in the Choptank River. This figure displays the longitudinal dissolved inorganic phosphorus gradient present in the Choptank River.

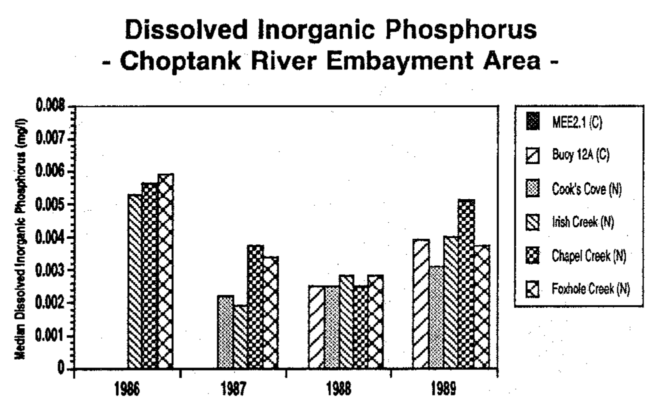


Figure VII-45. Comparisons of 1986-1989 growing season median dissolved inorganic phosphorus concentrations for the nearshore (N) and mid-channel (C) monitoring stations in the Choptank River Embayment Area.

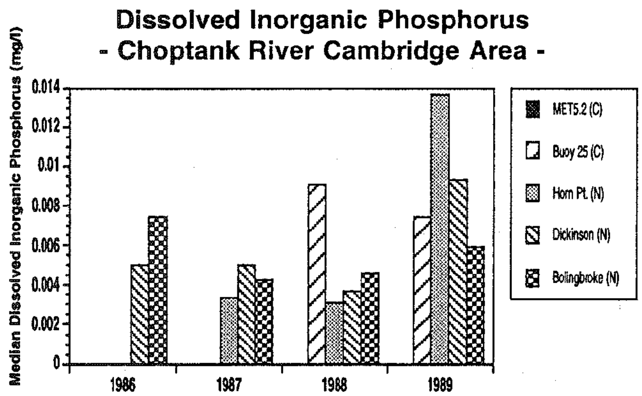


Figure VII-46. Comparisons of 1986-1989 growing season median dissolved inorganic phosphorus concentrations for the nearshore (N) and mid-channel (C) monitoring stations in the Choptank River Cambridge Area.

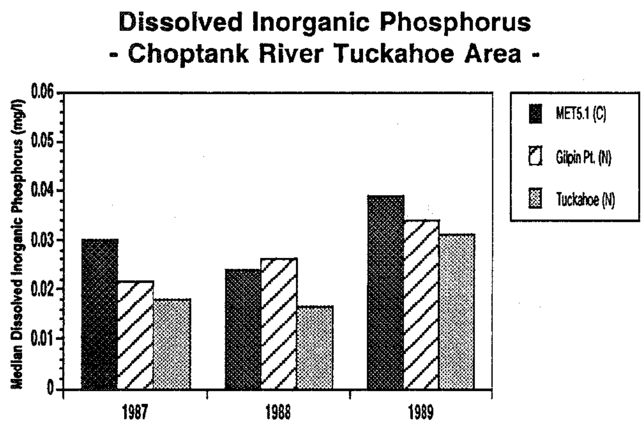


Figure VII-47. Comparisons of 1987-1989 growing season median dissolved inorganic phosphorus concentrations for nearshore (N) and mid-channel (C) monitoring stations in the Choptank River Tuckahoe Area.

with chlorophyll *a* levels often significantly greater in the mid-channel relative to nearshore. No consistent pattern of variation was apparent in 1989, and no significant differences were detected between the mid-channel and nearshore sites.

In the Cambridge and Tuckahoe areas, no consistent variation was detected between the nearshore and mid-channel sites (Figures VII-36, VII-38, and VII-39). Only three significant differences, all occurring in 1987, were detected between the mid-channel and nearshore sites (Tables VII-16 and VII-17). Two of the differences were in the Tuckahoe area where the two nearshore sites seemed to exhibit unusually low chlorophyll *a* levels in 1987 when compared to other years.

Dissolved Inorganic Nitrogen

In the Choptank embayment, little consistent variation was detected between the mid-channel and nearshore sites (Figures VII-40 and VII-41). A few statistically significant differences were found for dissolved inorganic nitrogen between the nearshore and mid-channel sites in the embayment, but these differences were not consistent from year to year (Table VII-18). Exploratory graphical analyses revealed that similar differences were also present among the nearshore stations although none of these differences were significant (Figure VII-41 and Table VII-18).

In the Cambridge area, dissolved inorganic nitrogen levels were highest at the mid-channel stations relative to the nearshore stations in each year (Figures VII-40 and VII-42). Some statistically significant differences were detected between the nearshore and mid-channel stations although these differences were not consistent from year to year (Table VII-19). Similar significant differences were detected among the nearshore sites in 1988. It is possible that effluent from the Cambridge wastewater treatment plant was influencing these observations by elevating dissolved inorganic nitrogen concentrations in mid-channel areas.

In the Tuckahoe area, dissolved inorganic nitrogen levels were found to be greater at mid-channel station MET5.1 relative to the two nearshore stations in each year (Figure VII-43). None of these observed differences, however, were statistically significant (Table VII-20).

Dissolved Inorganic Phosphorus

Only one statistically significant difference between mid-channel and nearshore levels of dissolved inorganic phosphorus was detected in the Choptank River (Tables VII-21 through VII-23). Exploratory graphical analyses for this river support the statistical findings, indicating little difference between the nearshore and mid-channel sites (Figures VII-44 through VII-47). Some problems were encountered with inadequate detection limits at the MDE sites, preventing the use of these data in the embayment and Cambridge areas.

Upper Chesapeake Bay

Water Temperature

Surface water temperatures were found to be nearly identical at adjacent nearshore and mid-channel stations, with

Table VII-9. Statistical comparisons of yearly growing season nearshore/mid-channel station data for light attenuation—Choptank River Embayment Area.

	Buoy 12A	Cook's Cove	Irish Creek	Chapel Creek	Foxhole Creek
MEE2.1	NS(1988-89)	NS(1987-89)	NS(1986-89)	NS(1986-89)	NS(1986-89)
Buoy 12A	****	NS(1988-89)	NS(1988-89)	NS(1988-89)	NS(1988-89)
Cook's Cove	****	****	NS(1987-89)	NS(1987-89)	NS(1987-89)
Irish Creek	****	****	****	NS(1986-89)	NS(1986-89)
Chapel Creek	****	****	****	****	NS(1986-87,89)

NS = not significant (p>.05)
ND = no data available

Table VII-10. Statistical comparisons of yearly growing season nearshore/mid-channel station data for light attenuation–Choptank River Cambridge Area.

	Buoy 25	Horn Point	Dickinson Bay	Bolingbroke Creek
MET5.2	NS(1988) p<.0001(1989)	NS(1987-89)	NS(1987-89) p<.005(1986)	NS(1987,89) p<.01(1986,88)
Buoy 25	****	NS(1988-89)	NS(1988) p<.02(1989)	p<.01(1988-89)
Horn Point	****	****	NS(1987-88) p<.025(1989)	NS(1987,89) p<.03(1988)
Dickinson Bay	****	****	****	NS(1986-89)

NS = not significant (p>.05)
ND = no data available

Table VII-11. Statistical comparisons of yearly growing season nearshore/mid-channel station data for light attenuation—Choptank River Tuckahoe Area.

	Gilpin Point	Tuckahoe Creek
MET5.1	NS(1986-88) p<.025(1989)	NS(1987-89)
Gilpin Point	****	NS(1987-89)

NS = not significant (p>.05)
ND = no data available

Table VII-12. Statistical comparisons of yearly growing season nearshore/mid-channel station data for total suspended solids—Choptank River Embayment Area.

	Buoy 12A	Cook's Cove	Irish Creek	Chapel Creek	Foxhole Creek
MEE2.1	p<.006(1988-89)	NS(1987,89) p<.05(1988)	NS(1986-88) p<.01(1989)	NS(1986-87) p<.03(1988-89)	NS(1986-89)
Buoy 12A	****	NS(1988-89)	NS(1989) p<.015(1988)	NS(1988-89)	NS(1988-89)
Cook's Cove	****	****	NS(1987-89)	NS(1987-89)	NS(1987-89)
Irish Creek	****	****	****	NS(1986,87,89) p<.015(1988)	NS(1986-89)
Chapel Creek	****	****	****	****	NS(86,87,89)

NS = not significant (p>.05)
ND = no data available

Table VII-13. Statistical comparisons of yearly growing season nearshore/mid-channel station data for total suspended solids—Choptank River Cambridge Area.

	Buoy 25	Horn Point	Dickinson Bay	Bolingbroke Creek
MET5.2	NS(1988) p<.0003(1989)	NS(1987-88) p<.01(1989)	NS(1988-89) p<.05(1986-87)	NS(1989) p<.05(1986-88)
Buoy 25	****	NS(1988-89)	NS(1988) p<.025(1989)	p<.014(1988-89)
Horn Point	****	****	NS(1987-88) p<.04(1989)	NS(1987) p<.03(1988-89)
Dickinson Bay	****	****	****	NS(1987-89) p<.01(1986)

NS = not significant (p>.05)
ND = no data available

Table VII-14. Statistical comparisons of yearly growing season nearshore/mid-channel station data for total suspended solids—Choptank River Tuckahoe Area.

	Gilpin Point	Tuckahoe Creek
MET5.1	NS(1987-89)	NS(1987-88) p<.014(1989)
Gilpin Point	****	NS(1987-89)

NS = not significant (p>.05)
ND = no data available

Table VII-15. Statistical comparisons of yearly growing season nearshore/mid-channel station data for chlorophyll *a*—Choptank River Embayment Area.

	Buoy 12A	Cook's Cove	Irish Creek	Chapel Creek	Foxhole Creek
MEE2.1	NS(1988-89)	NS(1989) p<.0025(1987-88)	NS(1986,89) p<.025(1987-88)	NS(1986,89) p<.005(1987-88)	NS(1986,89) p<.017(1987-88)
Buoy 12A	****	NS(1989) p<.015(1988)	NS(1989) p<.05(1988)	NS(1989) p<.01(1988)	NS(1989) p<.019(1988)
Cook's Cove	****	****	NS(1987-89)	NS(1987-89)	NS(1987-89)
Irish Creek	****	****	****	NS(1986-89)	NS(1986-89)
Chapel Creek	****	****	****	****	NS(1986-89) p<.05(1988)

NS = not significant (p>.05)
ND = no data available

Table VII-16. Statistical comparisons of yearly growing season nearshore/mid-channel station data for chlorophyll *a*—Choptank River Cambridge Area.

	Buoy 25	Horn Point	Dickinson Bay	Bolingbroke Creek
MET5.2	NS(1988-89)	NS(1986,88,89) p<.05(1987)	NS(1986-89)	NS(1986-89)
Buoy 25	****	NS(1988-89)	NS(1988-89)	NS(1988-89)
Horn Point	****	****	NS(1986-89)	NS(1986-89)
Dickinson Bay	****	****	****	NS(1986-89)

NS = not significant (p>.05)
ND = no data available

Table VII-17. Statistical comparisons of yearly growing season nearshore/mid-channel station data for chlorophyll *a*—Choptank River Tuckahoe Area.

	Gilpin Point	Tuckahoe Creek
MET5.1	NS(1986,88,89) p<.0001(1987)	NS(1988-89) p<.0001(1987)
Gilpin Point	****	NS(1987-89)

NS = not significant (p>.05)
ND = no data available

Table VII-24. Statistical comparisons of yearly growing season nearshore/mid-channel station data for the upper Chesapeake Bay.

Stations	Year	Kd	CHLA	TSS	DIN	DIP
Georgetown/MET3.1	1988	NS	ND	ND	ND	ND
	1989	NS	NS	NS	NS	NS
Piney (in)/Piney (out)	1988	NS	ND	ND	ND	ND
	1989	NS	ND	ND	ND	ND
Elk (in)/Elk (out)	1988	NS	ND	ND	ND	ND
	1989	NS	ND	ND	ND	ND
Elk (in)/MET2.3	1988	NS	ND	ND	ND	ND
	1989	NS	ND	ND	ND	ND
Havre D/Susquehanna	1988	NS	ND	ND	ND	ND
	1989	NS	ND	ND	ND	ND
Havre D/MCB1.1	1988	NS	ND	ND	ND	ND
	1989	NS	ND	ND	ND	ND
Havre D/Fishing (out)	1988	NS	ND	ND	ND	ND
	1989	NS	ND	ND	ND	ND
Havre D/Center Bay	1988	NS	ND	ND	ND	ND
	1989	NS	ND	ND	ND	ND
Fishing (in)/Susquehanna	1988	NS	ND	ND	ND	ND
	1989	NS	ND	ND	ND	ND
Fishing (in)/MCB1.1	1988	NS	ND	ND	ND	ND
	1989	NS	ND	ND	ND	ND
Fishing (in)/Fishing (out)	1988	NS	ND	ND	ND	ND
	1989	NS	ND	ND	ND	ND
Fishing (in)/Center Bay	1988	NS	ND	ND	ND	ND
	1989	NS	ND	ND	ND	ND

NS = not significant (p>.05)
ND = no data available

** Susquehanna = Log Pond
** Havre D = Outfall

some variability most likely due to different sampling times.

Salinity

Surface salinities were not available for the stations monitored by HCC in the upper Chesapeake Bay. Based upon existing segmentation schemes and the geographical proximity of the nearshore/mid-channel station pairs, it was assumed that the salinities between the nearshore/mid-channel station pairs were similar.

Light Attenuation Coefficient

No significant differences in light attenuation coefficient levels were detected between nearshore and mid-channel stations in the upper Chesapeake Bay (Table VII-24). Light levels were found to be nearly identical between adjacent nearshore and mid-channel stations in the two years that data were available (Figures VII-48 through VII-51). This result suggests that light levels do not vary significantly between nearshore and mid-channel sites in the upper Chesapeake Bay.

Total Suspended Solids

In the upper Chesapeake Bay, nearshore total suspended solids data were collected for only one year at a single location in the Sassafras River (Georgetown). Comparisons between the nearshore station and an adjacent mid-channel station revealed no significant differences in the levels of total suspended solids between the two stations (Figure VII-52 and Table VII-24).

Chlorophyll *a*

Nearshore chlorophyll *a* data for the upper Chesapeake Bay were collected for only one year at a single location in the Sassafras River (Georgetown). Comparisons between the nearshore station and an adjacent mid-channel station revealed no statistically significant differences in chlorophyll *a* levels between the two stations (Figure VII-53 and Table VII-24).

Dissolved Inorganic Nitrogen

Dissolved inorganic nitrogen data were only available for one year at one location in the nearshore station (Georgetown) due to analytical problems. Comparisons between the nearshore and mid-channel stations located in the Sassafras River revealed no significant difference in the levels of dissolved inorganic nitrogen between the two stations (Figure VII-54 and Table VII-24).

Dissolved Inorganic Phosphorus

In the upper Bay, nearshore dissolved inorganic phosphorus data were only available for one year at one location (Georgetown) because of analytical problems. Comparisons between the nearshore station and an adjacent mid-channel station located in the Sassafras revealed no significant difference in the levels of dissolved inorganic phosphorus between the two stations (Figure VII-55 and Table VII-24).

Discussion

Light Attenuation Coefficient

Comparison of Secchi depths and photosynthetically active radiation (PAR) attenuation using light sensors correlated with recent research which indicated that measurements of transparency by Secchi disk are as accurate and precise as estimates of light attenuation calculated from light sensor readings in the sea (Megard and Berman 1989). Based upon these results, Secchi depth readings provided an acceptable substitute for light sensor readings in Chesapeake Bay for the purposes of this application, as long as water depths exceeded Secchi depths.

Overall, comparisons of mid-channel and nearshore light attenuation coefficients yielded the closest agreement of all variables examined (Figure VII-56). Relative to the

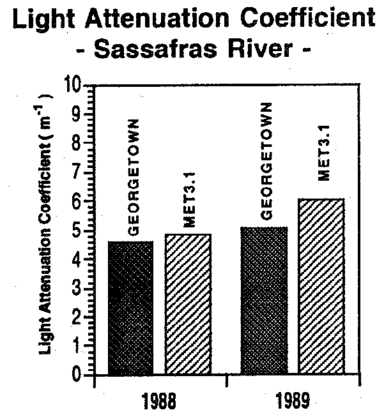


Figure VII-48. Comparison of 1988-1989 growing season median light attenuation coefficients for nearshore (■) and mid-channel (▨) monitoring stations in the Sassafras River.

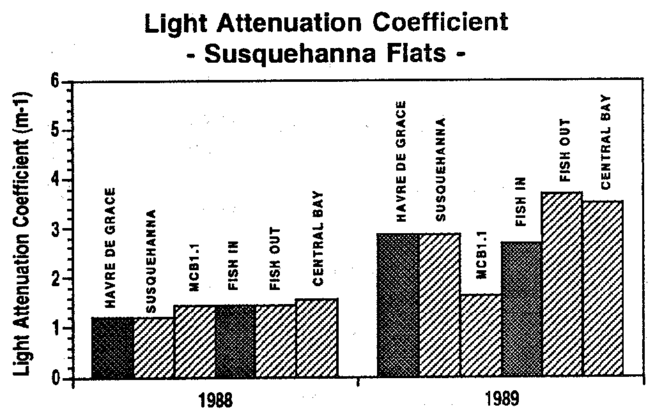


Figure VII-49. Comparisons of 1988-1989 growing season median light attenuation coefficients at nearshore (■) and mid-channel (▨) monitoring stations in the Susquehanna Flats.

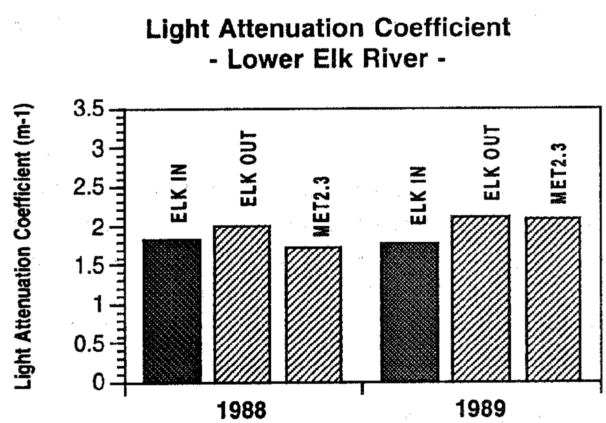


Figure VII-50. Comparisons of 1988-1989 annual growing season median light attenuation coefficients at nearshore (■) and mid-channel (▨) monitoring stations in the lower Elk River.

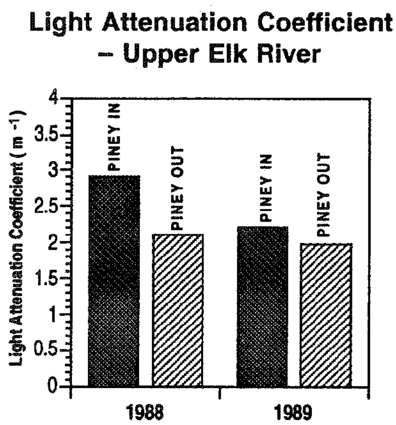


Figure VII-51. Comparisons of 1988-1989 growing season median light attenuation coefficients at nearshore (■) and mid-channel (▨) monitoring stations in the upper Elk River.

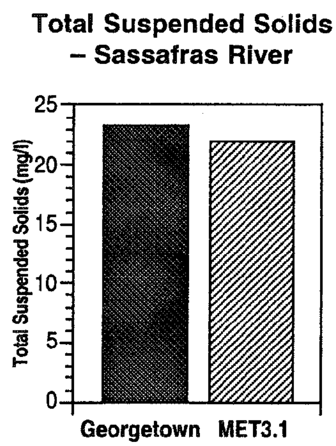


Figure VII-52. Comparisons of 1989 growing season median total suspended solids concentrations for nearshore (■) and mid-channel (▨) monitoring stations in the Sassafras River.

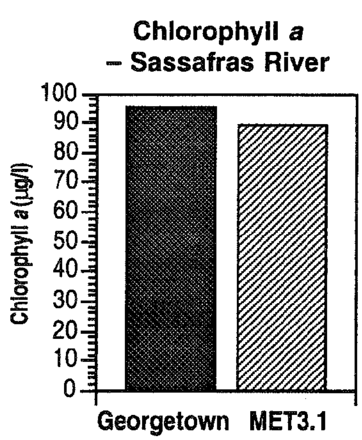


Figure VII-53. Comparisons of 1989 growing season median chlorophyll *a* concentrations for nearshore (■) and mid-channel (▨) monitoring stations in the Sassafras River.

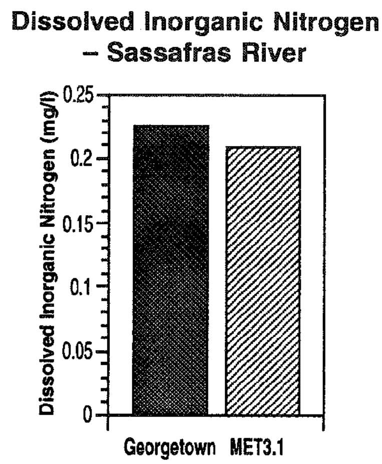


Figure VII-54. Comparisons of 1989 growing season median dissolved inorganic nitrogen concentrations for nearshore (■) and mid-channel (▨) monitoring stations in the Sassafras River.

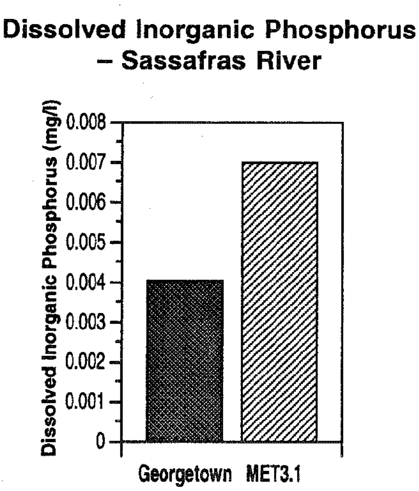


Figure VII-55. Comparisons of 1989 growing season median dissolved inorganic phosphorus concentrations for nearshore (■) and mid-channel (▨) monitoring stations in the Sassafras River.

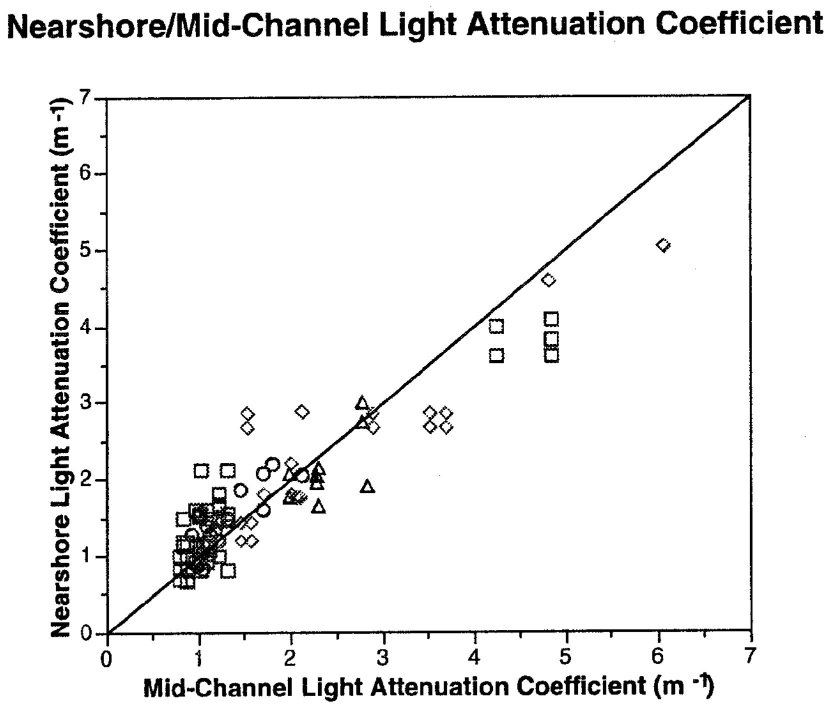


Figure VII-56. Comparisons of paired nearshore and mid-channel growing season median light attenuation coefficient data from the York River (○), upper Potomac River (△), Choptank River (□), and upper Chesapeake Bay (◇).

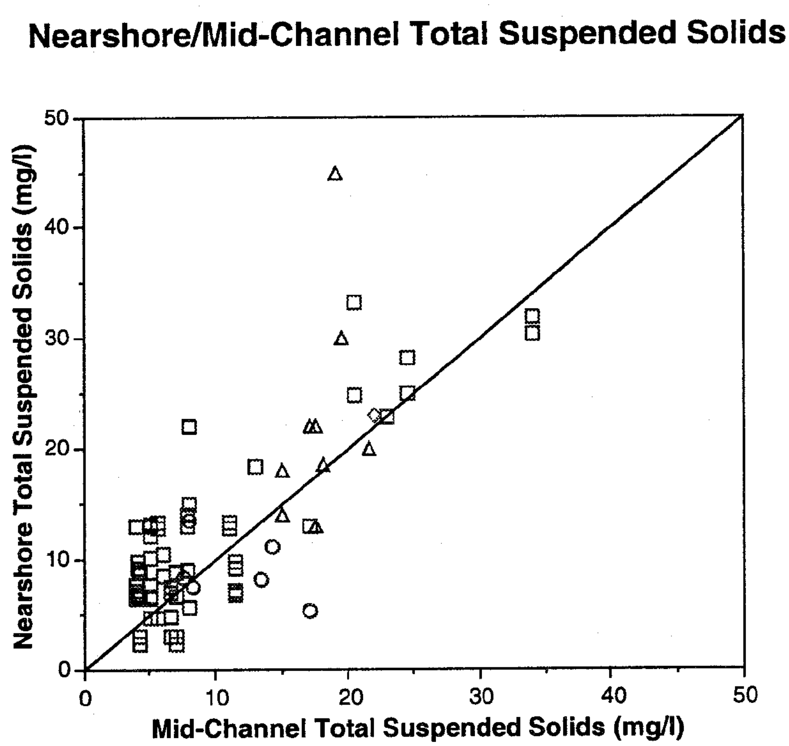


Figure VII-57. Comparisons of paired nearshore and mid-channel growing season median total suspended solids data from the York River (○), upper Potomac River (△), Choptank River (□), and upper Chesapeake Bay (◇).

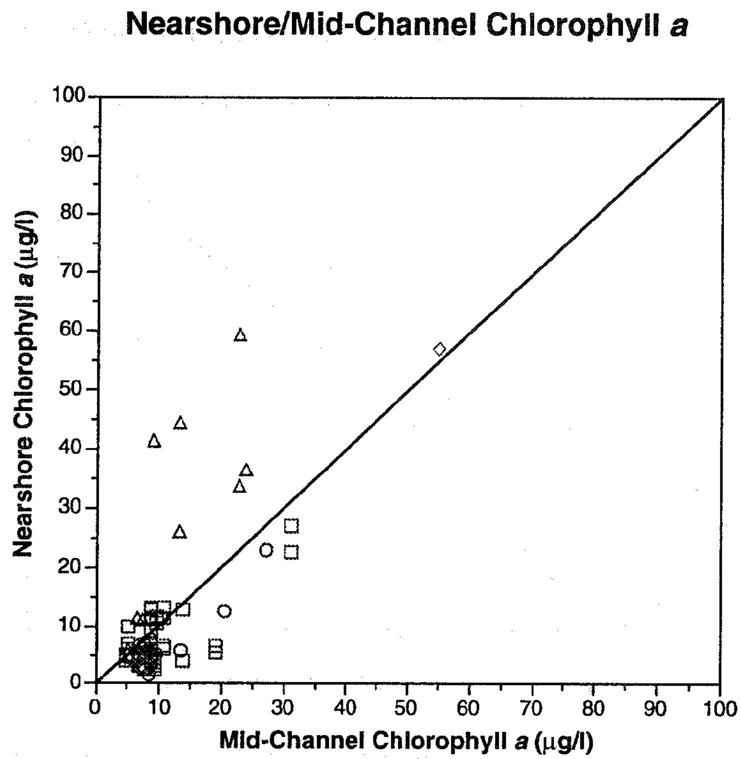


Figure VII-58. Comparisons of paired nearshore and mid-channel growing season median chlorophyll *a* data from the York River (○), upper Potomac River (△), Choptank River (□), and upper Chesapeake Bay (◇).

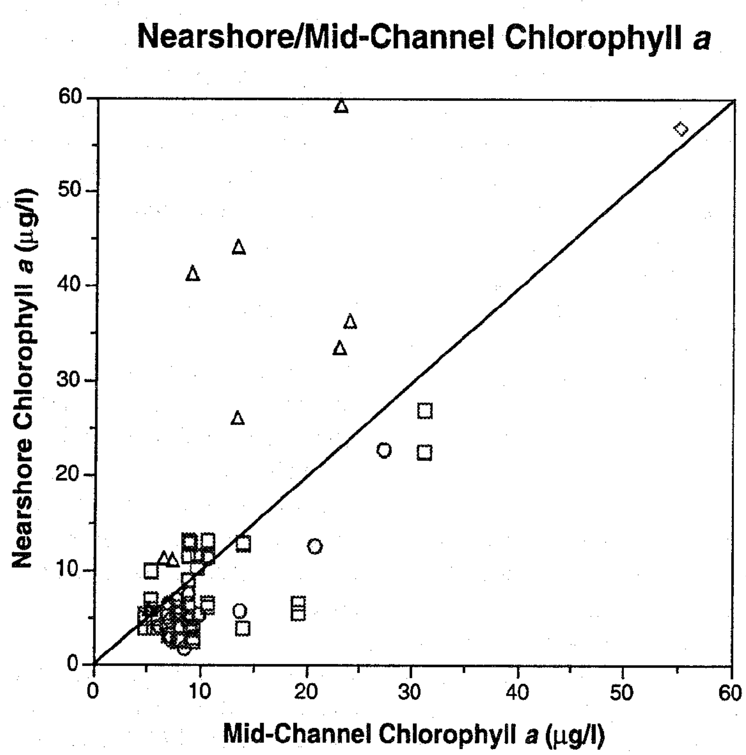


Figure VII-59. Comparisons of paired nearshore and mid-channel growing season median chlorophyll *a* data from the York River (○), upper Potomac River (△), Choptank River (□), and upper Chesapeake Bay (◇). Expanded scale from Figure VII-58.

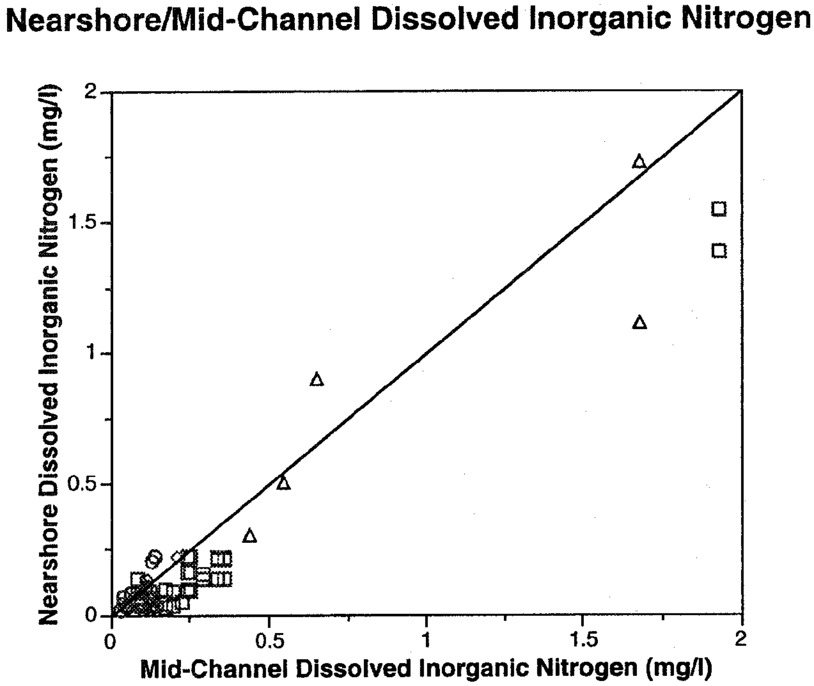


Figure VII-60. Comparisons of paired nearshore and mid-channel growing season median dissolved inorganic nitrogen data from the York River (○), upper Potomac River (△), Choptank River (□), and upper Chesapeake Bay (◇).

light attenuation coefficient SAV habitat requirement for one meter restoration, data from adjacent nearshore and mid-channel stations yielded identical classifications of meeting/not meeting the habitat requirements 87.5% of the time (Table VII-25). As with total suspended solids, considerable variability over the growing season was observed in the discrete measures of light attenuation reported here. This is not surprising considering the number of factors, both physical and biological, that can influence the concentration of particles in the water column and, therefore, the attenuation of light. However, given the constraints of the sampling it appears that mid-channel Secchi depth observations provide an adequate model of nearshore conditions when measured over a seasonal time frame.

Total Suspended Solids

Total suspended solids were characterized by considerable variability within the growing season in both the nearshore and mid-channel areas. Because of the high variability and small sample populations, differences between sites may have been difficult to detect. Relative to the total suspended solids SAV habitat requirements for one meter restoration, data from adjacent nearshore and mid-channel stations yielded identical classifications 65.7% of the time (Table VII-25). Overall, no strong bias between nearshore and mid-channel sites was observed (Figure VII-57). Where statistically significant differences were found they generally indicated higher levels in nearshore locations. This suggests possible inputs due to run-off or resuspension due to wave action in certain shallow areas. Some occurrences of higher nearshore total suspended solids levels in the Potomac may have been due to increased organic particulate matter such as phytoplankton (see chlorophyll *a* section below). Particulates contribute to total suspended solids and have the ability to attenuate sunlight before it reaches SAV.

Chlorophyll a

Differences in chlorophyll *a* concentrations between mid-channel and nearshore sites were most pronounced in embayments and coves of the Potomac River (Figures VII-58 and VII-59). It is possible that differing residence times or entrapment of wind-blown surface films may play an important role in causing differences in phytoplankton biomass between mid-channel and nearshore sites in these areas.

In most of the sites studied, chlorophyll *a* levels were comparable between nearshore and mid-channel sites (Figures VII-58 and VII-59). Relative to the chlorophyll *a* SAV habitat requirements for one meter restoration, data from adjacent nearshore and mid-channel stations yielded identical classifications 81.2% of the time (Table VII-25).

Therefore, mid-channel monitoring appears to provide a suitable measure of chlorophyll *a* in nearshore environments under most circumstances. However, phytoplankton generally has patchy distributions. This natural variability can cause differences between nearshore and mid-channel sites as well as between different nearshore sites.

Dissolved Inorganic Nitrogen

The general lack of significant differences observed among the paired stations for dissolved inorganic nitrogen in this study suggests that mid-channel monitoring may be useful for assessing the levels in the nearshore where the data are summarized over growing seasons (Figures VII-60 and VII-61). Relative to the dissolved inorganic nitrogen SAV habitat requirements for one meter restoration, data from adjacent nearshore and mid-channel stations yielded identical classifications 82.8% of the time (Table VII-25). The fact that there were few significant differences in the paired data sets, however, does not necessarily demonstrate that dissolved inorganic nitrogen levels in mid-channel and nearshore regions are generally the same.

Over the SAV growing season, dissolved inorganic nitrogen levels typically range from very high in spring to very low at the end of summer, especially in mesohaline areas. This wide range contributes to low power in the statistical tests, making differences between sites difficult to identify with a seasonal aggregation of data. This large range of dissolved inorganic nitrogen levels during the growing season likewise contributes to uncertainty in the habitat requirements themselves. Localized differences were found at several locations, including the embayment and Cambridge areas on the Choptank River. These differences may reflect point source inputs of dissolved inorganic nitrogen.

Dissolved Inorganic Phosphorus

The comparison of dissolved inorganic phosphorus levels in mid-channel and nearshore areas was limited in several regions by problems with high detection limits for the mid-channel data. Where this was not a problem, the results suggest that levels in mid-channel and nearshore areas are comparable with few statistically significant differences or consistent biases (Figure VII-62). Relative to the dissolved inorganic phosphorus SAV habitat requirements for one meter restoration, data from adjacent nearshore and mid-channel stations yielded identical classifications 75% of the time (Table VII-25).

Other Reported Results

Results from a statistical comparison of mainstem nearshore and mid-channel water quality data are summarized here (Chesapeake Bay Program 1992) to demonstrate that the findings from the tributary study areas presented in this report can be applied to monitoring data from the mainstem Bay. These mainstem nearshore/mid-channel comparisons used the same exploratory data analysis and statistical analysis techniques employed by Bieber and Moore in the tributary studies reported in this chapter.

Table VII-25. Classification rate of mid-channel relative to nearshore stations using SAV habitat requirements for one meter restoration.

	Low	Same	High	Total
Light attenuation coefficient	3 (7.5%)	35 (87.5%)	2 (5%)	40 (100%)
Total suspended solids	10 (28.6%)	23 (65.7%)	2 (5.7%)	35 (100%)
Chlorophyll *a*	3 (9.4%)	26 (81.2%)	3 (9.4%)	32 (100%)
Dissolved inorganic nitrogen	0 (0%)	24 (82.8%)	5 (17.2%)	29 (100%)
Dissolved inorganic phosphorus	4 (16.7%)	18 (75.0%)	2 (8.3%)	24 (100%)
TOTAL	20 (12.2%)	126 (77.3%)	17 (10.4%)	163 (100%)

Low = Nearshore does not meet habitat requirements for one meter restoration; mid-channel meets habitat requirements for one meter restoration.
Same = Both nearshore and mid-channel do or do not meet habitat requirements for one meter restoration.
High = Nearshore meets habitat requirements for one meter restoration; mid-channel does not meet habitat requirements for one meter restoration.

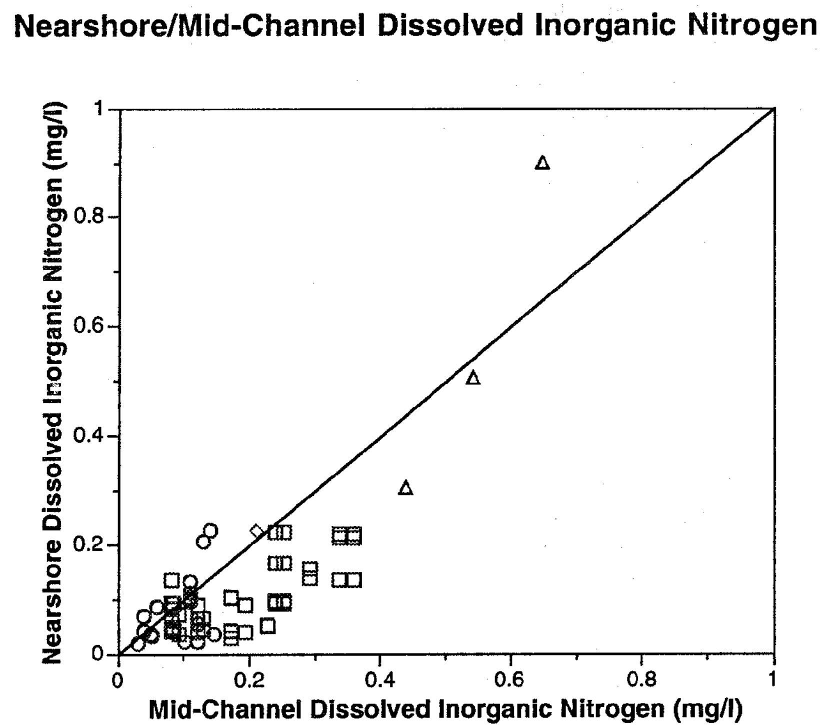


Figure VII-61. Comparisons of paired nearshore and mid-channel growing season median dissolved inorganic nitrogen data from the York River (○), upper Potomac River (△), Choptank River (□), and upper Chesapeake Bay (◇). Expanded scale from Figure VII-60.

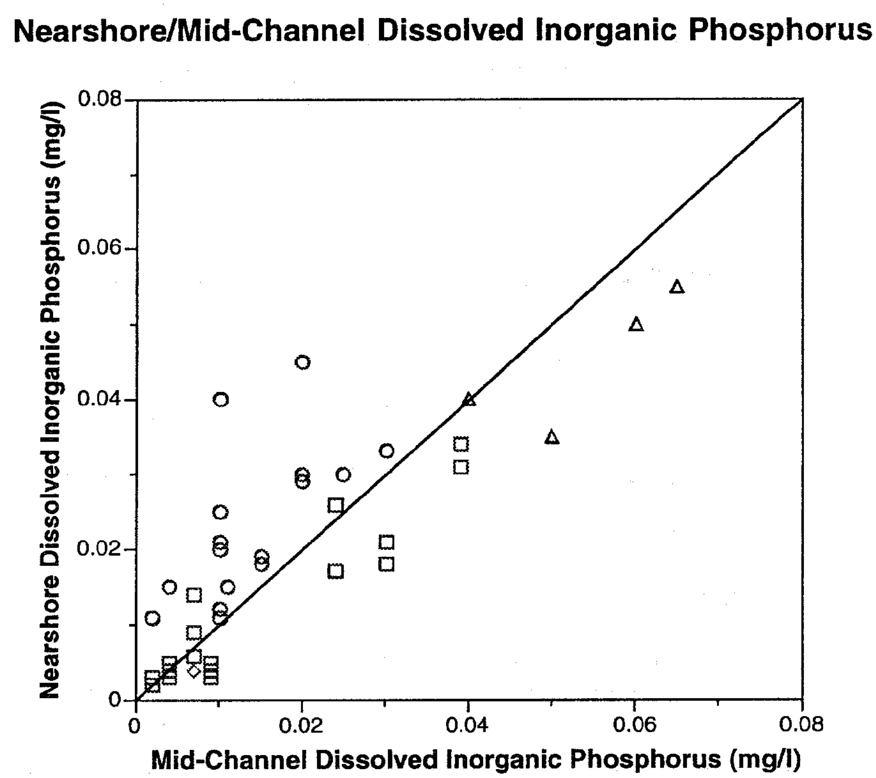


Figure VII-62. Comparisons of paired nearshore and mid-channel growing season median dissolved inorganic phosphorus data from the York River (○), upper Potomac River (△), Choptank River (□), and upper Chesapeake Bay (◇).

Comparisons used April-October seasonal medians from the surface layer for all five SAV habitat requirements (Secchi depth as a substitute for light attenuation coefficient, total suspended solids, chlorophyll *a*, dissolved inorganic nitrogen, and dissolved inorganic phosphorus). The nearshore and mid-channel data compared were from seven east-west monitoring station transects located in the middle Chesapeake Bay. There were no statistically significant differences between mid-channel and eastern stations for any of the listed parameters in any transects. For the mid-channel and western station comparisons, there were statistically significant differences ($p < 0.01$) for four of these five parameters (all but dissolved inorganic nitrogen) in three of the six transects studied (CB4.1 through CB4.3).

The results still support using mid-channel data to characterize water quality in nearshore habitats for two reasons. First, the western stations in two of the three transects involved (CB4.2W and CB4.3E) do not characterize potential SAV habitat (Appendix A, Tables A-1 and A-2). Most of the potential SAV habitat in this area of the Bay is on the Eastern Shore. Second, the difference between seasonal median values at the western and central stations were small in all three transects. For all four parameters, the median difference over six years between west and center April-October medians was near the analytical precision for that parameter: dissolved inorganic phosphorus = 0.0012-0.0014 mg/l, chlorophyll *a* = 2.4-3.3 ug/l, total suspended solids = 1.3-1.8 mg/l, and Secchi depth = 0.2-0.5 m.

Findings

Results from this study indicate that data collected in the mid-channel of Chesapeake Bay tributaries may be successfully used to characterize seasonal levels of the investigated water quality variables in adjacent nearshore areas. Statistically significant differences do exist in some cases between the nearshore and mid-channel stations, but in most instances, consistent biases over the different years and sites were not evident. Where data were available for several nearshore sites in a particular region, the variability among these sites was comparable to the variability between the nearshore and mid-channel sites. Where data were not subject to error induced by different sampling times and analytical methods, few significant differences were found.

While the results of this study do support the use of mid-channel data to characterize nearshore areas over seasonal time frames, they are not meant to imply a predictive relationship between nearshore and mid-channel observations. Rather, it is proposed that seasonal aggregations of mid-channel water quality data can provide reliable estimates of nearshore water quality conditions, at least for those variables presented here (light attenuation coefficient, total suspended solids, chlorophyll *a*, dissolved inorganic nitrogen, and dissolved inorganic phosphorus). Although nearshore observations of the investigated water quality variables do tend to correspond closely to observations in adjacent mid-channel areas, no predictive relationships were investigated.

This study has answered many of the questions about the comparability of nearshore and mid-channel water quality as they relate to SAV growth requirements. Additional analyses would be required to assess the ability of mid-channel data to characterize nearshore locations for other variables and/or different time and space scales. If the need for these comparisons is great in the future, then it may be desirable to initiate specific studies that are designed to better control sources of variability that were encountered in this study.

Chapter VIII
Future Needs

The submerged aquatic vegetation (SAV) habitat requirements presented in this report were generated from a variety of studies by different investigators. They represent minimal water quality conditions that simply support SAV survival, and do not provide criteria for species diversity, biomass, or functional value. As such, the habitat requirements could be further developed to incorporate these other aspects of SAV distribution. Future research could also: a) define the time scales of SAV responses; b) further quantify the components of light attenuation; and, c) employ SAV transplants to further test SAV survival/light attenuation/water depth relationships.

Future research efforts to specifically address water quality effects on SAV should include laboratory, mesocosm, field and modeling efforts, and a coordination of the research efforts to insure consistency of sampling design, analytical methodology, and data analyses. While the empirical results used here are good predictors of SAV survival in Chesapeake Bay, it is unknown how effective they may be in other coastal bays. It would be of interest to test the Chesapeake Bay SAV habitat requirements in other systems with the goal of developing more generic SAV habitat requirements that could be used in other locations. Both the actual habitat requirements and the habitat requirement approach can be used in this context as models for future studies.

The use of SAV distributions as integrating "light meters" over the appropriate temporal and spatial scales could be further refined. The lag time, or delay in SAV response, to changes in ambient light regimes needs to be established in order to better interpret SAV distributional data with regard to water quality. An ongoing SAV trends analysis will address the time lag between water quality improvements and SAV resurgences in some areas of the Bay. Some SAV species can withstand relatively long periods of low light availability before exhibiting a growth or survival response, so a time scale of SAV response would be helpful in applying habitat requirements. In addition, the rates of colonization of SAV into unvegetated areas need to be quantified so that SAV resurgences can be predicted from proposed water quality improvements. A model of SAV growth that incorporates seasonal growth responses to changes in light attenuation would be useful in this context. Since the timing and duration of low light events (e.g., resuspension, high runoff periods) will affect SAV responses, an understanding of seasonal dynamics of growth and light response would aid in developing management strategies.

A more complete knowledge of the sources and causes of the various light attenuation components would help in developing management strategies for reducing light attenuation in Chesapeake Bay. The epiphyte component of light attenuation needs further research attention, particularly with regard to nutrient enrichments. The empirical connection between dissolved water column nutrients (dissolved inorganic nitrogen and dissolved inorganic phosphorus) and SAV survival needs to be more fully explored. Epiphytes do not have the constant light absorption characteristics due to differences in species composition and epiphyte trapping of fine-grained inorganic material. Thus, the light attenuation characteristics, rather than just epiphyte biomass, need to be quantified as a function of nutrient conditions. The interaction of epiphytes and phytoplankton, both of which respond to water column nutrient availability, also requires research attention. In addition, the interaction of the organic component of light absorption (principally epiphytes and phytoplankton) with the inorganic component is important in determining SAV responses.

For application of SAV habitat requirements in a management context, the standing stock measurements of nutrients (dissolved inorganic nitrogen and dissolved inorganic phosphorus), total suspended solids and chlorophyll *a* need to be translated into human activities that affect loading rates of sediments and nutrients. Further development of the habitat requirements approach could address the issue of loading rates. This could begin to be addressed by considering the total nutrient amounts, not just dissolved inorganic nutrient concentrations.

Chesapeake Bay is unique in the wealth of SAV distributional data available, and continued baywide surveys are necessary in order to assess SAV responses to improvements in water quality. Both remote sensing techniques and ground-truthing are required for accurate surveys. Improvements in techniques that are forthcoming with the recent technological advances in geographic information systems will need to be integrated with current techniques in a manner that insures consistency. Baywide water quality monitoring also needs to be continued to assess SAV responses to changes in water quality with a particular emphasis on maintaining appropriate lower detection limits for the dissolved nutrient parameters. The ongoing Chesapeake Bay Monitoring Program, which focuses on the mid-channel portions of the Bay mainstem and tidal tributaries, needs to be supplemented with a sampling program in the shallows where SAV grow to ensure that mid-channel data continues to adequately characterize shallow habitats.

The use of experimental SAV transplants has been valuable for distinguishing water quality impacts from availability of propagules for establishment of SAV. Further use of this approach could establish the validity of the habitat requirements in a variety of locations throughout Chesapeake Bay. In particular, transplants of various SAV species along well-defined depth gradients would help to further quantify any differences in light attenuation characteristics that may exist between different SAV species with different growth morphologies (e.g., canopy-forming versus meadow-forming SAV) or different physiological tolerances to low light conditions.

The empirical approach used to develop SAV habitat requirements allows for predictive capacity without detailed quantification of the precise nature of SAV/water quality interactions. Since SAV in Chesapeake Bay is less than 10% of the Tier III SAV distribution restoration target and less than 53% of the Tier I SAV distribution restoration target, there is a need to provide water quality guidelines before a more complete understanding of the complex ecological interactions is reached. Notwithstanding future research efforts to better quantify the individual SAV water quality parameter interactions accounted for by the SAV habitat requirements, the SAV habitat requirements developed through this synthesis can, at this time, be directly integrated into and applied within ongoing Bay restoration management programs.

Finally, we need to maintain continuous interactions and feedback between the researchers who continue to investigate SAV/water quality interactions and the managers who are responsible for ultimate protection, restoration, and enhancement of living resources. Continued research and monitoring of water quality and SAV, coupled with management towards specific restoration targets, is paramount if these resources are to be part of our future.

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Appendix A — Table 1

Table A-1. Validation of the baywide application of SAV habitat requirements: 1987 SAV distribution and water quality conditions by monitoring program station.

Station	Basin	Salinity	Kd	TSS	CHLA	DIN	DIP	HR Ratio	SAV	Comments
CB1.1	Up. Mainstem	Tidal Fresh	1.63	6.8	9.7	0.981	0.004	4/4	Y	
CB2.1	Up. Mainstem	Oligohaline	2.42 >	17.8 >	11.0	0.87	0.009	2/4	N	
CB2.2	Up. Mainstem	Oligohaline	2.12 >	10.1	7.3	0.747	0.013	3/4	N	SAV present within Still Pond and Churns Creek
CB3.1	Up. Mainstem	Mesohaline	1.81 >	7.9	10.0	0.538 >	0.009	3/5	N	
CB3.2	Up. Mainstem	Mesohaline	1.08	4.5	6.0	0.431 >	0.009	4/5	N	Sparse SAV present from Swan Pt. to Rock Hall Harbor
CB3.3C	Up. Mainstem	•	•	•	•	•	•	•	•	Doesn't characterize existing/potential SAV habitat
CB3.3E	Up. Mainstem	Mesohaline	1.17	6.8	16.9 >	0.219 >	0.007	3/5	N	
CB3.3W	Up. Mainstem	Mesohaline	1.45	7.2	14.7	0.279 >	0.009	4/5	N	
CB4.1C	Up. Mainstem	•	•	•	•	•	•	•	•	Doesn't characterize existing/potential SAV habitat
CB4.1E	Up. Mainstem	Mesohaline	0.86	4.2	10.7	0.166 >	0.004	4/5	N	SAV present from Kent Pt. to Long Pt. Harbor Cove North
CB4.1W	Up. Mainstem	Mesohaline	1.12	5.5	13.5	0.208 >	0.007	4/5	N	
CB4.2C	Up. Mainstem	•	•	•	•	•	•	•	•	Doesn't characterize existing/potential SAV habitat
CB4.2E	Up. Mainstem	Mesohaline	0.73	4.2	10.3	0.159 >	0.004	4/5	N	SAV present from Black Walnut Pt. north
CB4.2W	Up. Mainstem	•	•	•	•	•	•	•	•	Doesn't characterize existing/potential SAV habitat
CB4.3C	Up. Mainstem	•	•	•	•	•	•	•	•	Doesn't characterize existing/potential SAV habitat
CB4.3E	Up. Mainstem	Mesohaline	0.81	4.0	9.2	0.144	0.005	5/5	N	
CB4.3W	Up. Mainstem	•	•	•	•	•		•	•	Doesn't characterize existing/potential SAV habitat
CB4.4	Up. Mainstem	Mesohaline	0.91	5.2	13.1	0.062	0.004	5/5	N	Potential SAV habitat only on eastern shore
CB5.1	Up. Mainstem	Mesohaline	0.91	5.3	12.7	0.086	0.004	5/5	N	SAV present along Barren Island
CB5.2	Up. Mainstem	•	•	•	•	•	•	•	•	Doesn't characterize existing/potential SAV habitat
CB5.3	Up. Mainstem	•	•	•	•	•	•	•	•	Doesn't characterize existing/potential SAV habitat
CB5.4	L. Mainstem	Mesohaline	0.78	6.0	11.7	0.064	0.01	5/5	Y	
CB5.4W	L. Mainstem	Mesohaline	1.04	7.0	11.7	0.066	0.01	5/5	Y	

Table A-1. Continued

Station	Basin	Salinity	Kd	TSS	CHLA	DIN	DIP	HR Ratio	SAV	Comments
CB5.5	L. Mainstem	Mesohaline	0.78	5.5	11.6	0.033	0.01	5/5	Y	SAV present in Fleets Bay
CB6.1	L. Mainstem	•	•	•	•	•	•	•	•	Doesn't characterize existing/potential SAV habitat
CB6.2	L. Mainstem	Polyhaline	0.73	6.0	6.9	0.123	0.011	5/5	Y	Sparse SAV around Milford Haven and Eastern Shore
CB6.3	L. Mainstem	Polyhaline	0.97	11.0	10.5	0.086	0.011	5/5	N	Station only characterizes western shore SAV habitat
CB6.4	L. Mainstem	•	•	•	•	•	•	•	•	Doesn't characterize existing/potential habitat
CB7.1	L. Mainstem	Polyhaline	0.97	8.0	15.6 >	0.061	0.011	4/5	Y	CHLA habitat requirement exceeded by < 2 µg/l
CB7.1N	L. Mainstem	Polyhaline	1.04	9.0	17.8 >	0.069	0.01	4/5	Y	CHLA habitat requirement exceeded by < 3 µg/l
CB7.1S	L. Mainstem	Polyhaline	0.97	7.0	10.8	0.086	0.011	5/5	Y	
CB7.2	L. Mainstem	•	•	•	•	•	•	•	•	Doesn't characterize existing/potential SAV habitat
CB7.2E	L. Mainstem	Polyhaline	0.69	5.0	10.6	0.035	0.011	5/5	Y	Abundant SAV distribution
CB7.3	L. Mainstem	•	•	•	•	•	•	•	•	Doesn't characterize existing/potential SAV habitat
CB7.3E	L. Mainstem	Polyhaline	0.78	5.9	7.6	0.034	0.005	5/5	Y	
CB7.4	L. Mainstem	•	•	•	•	•	•	•	•	Doesn't characterize existing/potential SAV habitat
CB7.4N	L. Mainstem	•	•	•	•	•	•	•	•	Doesn't characterize existing/potential SAV habitat
CB8.1	L. Mainstem	•	•	•	•	•	•	•	•	Doesn't characterize existing/potential SAV habitat
CB8.1E	L. Mainstem	•	•	•	•	•	•	•	•	Doesn't characterize existing/potential SAV habitat
EE1.1	Eastern Bay	Mesohaline	0.69	4.0	5.4	0.156 >	0.006	4/5	Y	DIN habitat requirement exceeded
EE2.1	Choptank	Mesohaline	0.85	7.0	8.1	0.111	0.006	5/5	Y	
EE2.2	Little Choptank	Mesohaline	0.91	7.0	8.1	0.1	0.008	5/5	Y	Sparse SAV distribution
EE3.0	Honga	Mesohaline	1.81 >	24.0 >	8.2	0.128	0.006	3/5	N	
EE3.1	Tangier Sound	Mesohaline	1.45	17.0 >	9.0	0.096	0.006	4/5	N	SAV present along Bloodsworth Island
EE3.2	Tangier Sound	Mesohaline	1.12	9.0	6.3	0.106	0.006	5/5	Y	Abundant SAV distribution
EE3.3	Pocomoke Snd.	Mesohaline	1.81 >	18.5 >	7.3	0.082	0.006	3/5	Y	SAV in lower Pocomoke Sound
EE3.4	Tangier Sound	Mesohaline	1.61 >	12.5	12.1	0.062	0.01	4/5	Y	
EE3.5	Tangier Sound	Mesohaline	1.32	9.5	10.0	0.054	0.01	5/5	Y	

Table A-1. Continued

Station	Basin	Salinity	Kd	TSS	CHLA	DIN	DIP	HR Ratio	SAV	Comments
WE4.1	Mobjack Bay	Polyhaline	1.21	10.0	9.8	0.047	0.01	5/5	Y	Abundant SAV throughout Mobjack Bay
WE4.2	York River	Polyhaline	0.97	5.0	9.1	0.049	0.011	5/5	Y	Abundant SAV distribution
WE4.3	Poquoson	Polyhaline	0.97	9.0	11.0	0.032	0.01	5/5	Y	Abundant SAV distribution
WE4.4	Back	Polyhaline	1.12	10.0	7.5	0.028	0.01	5/5	Y	Abundant SAV distribution
ET1.1	Northeast	Oligohaline	3.63 >	27.0 >	33.5 >	0.283	0.004	1/4	N	
ET2.1	C&D Canal	•	•	•	•	•	•	•	•	Doesn't characterize existing/potential SAV habitat
ET2.2	Bohemia	Oligohaline	4.83 >	38.0 >	41.3 >	0.14	0.004	1/4	N	
ET2.3	Elk	Oligohaline	2.42 >	28.5 >	5.7	1.069	0.026 >	1/4	Y	Sparse SAV distribution
ET3.1	Sassafras	Oligohaline	4.83 >	30.0 >	54.6 >	0.072	0.004	1/4	N	
ET4.1	Chester	Mesohaline	6.04 >	80.0 >	61.3 >	0.21 >	0.008	1/5	N	
ET4.2	Chester	Mesohaline	0.97	4.0	5.4	0.31 >	0.008	4/5	Y	
ET5.1	Choptank	Mesohaline	4.83 >	40.5 >	19.4 >	0.36 >	0.031 >	0/5	N	
ET5.2	Choptank	Mesohaline	1.21	6.0	3.3	0.178 >	0.014 >	3/5	Y	Upriver limit of SAV within the Choptank
ET6.1	Nanticoke	Mesohaline	2.9 >	27.5 >	17.9 >	0.618 >	0.014 >	0/5	N	
ET6.2	Nanticoke	Mesohaline	2.9 >	28.0 >	11.7	0.15 >	0.008	2/5	N	
ET7.1	Wicomico	Mesohaline	2.42 >	24.0 >	8.3	0.125	0.015 >	2/5	N	
ET8.1	Manokin	Mesohaline	2.07 >	27.0 >	10.1	0.048	0.007	3/5	Y	
ET9.1	B. Annemessex	Mesohaline	1.32	12.0	8.3	0.048	0.004	5/5	Y	
ET10.1	Pocomoke	Mesohaline	3.63 >	16.0 >	6.2	0.564 >	0.038 >	1/5	N	
WT1.1	Bush	Oligohaline	3.88 >	27.5 >	21.7 >	0.278	0.004	1/4	N	
WT2.1	Gunpowder	Oligohaline	3.26 >	18.5 >	16.3 >	0.182	0.004	1/4	N	
WT3.1	Middle	Oligohaline	2.66 >	12.5	18.6 >	0.208	0.004	2/4	Y	
WT4.1	Back	Oligohaline	4.83 >	34.0 >	87.8 >	3.4	0.031 >	0/4	N	
WT5.1	Patapsco	Mesohaline	1.81 >	8.0	5.8	0.77 >	0.016 >	2/5	N	Upper Patapsco not existing/potential SAV habitat
WT6.1	Magothy	Mesohaline	1.45	8.0	13.3	0.124	0.006	5/5	N	Sparse SAV
WT7.1	Severn	Mesohaline	1.45	9.0	15.3 >	0.194 >	0.009	3/5	N	

Table A-1. Continued

Station	Basin	Salinity	Kd	TSS	CHLA	DIN	DIP	HR Ratio	SAV	Comments
WT8.1	South	Mesohaline	1.81 >	6.0	12.5	0.064	0.037 >	3/5	N	
WT8.2	Rhode	Mesohaline	1.81 >	16.0 >	16.4 >	0.042	0.01	2/5	N	
WT8.3	West	Mesohaline	1.81 >	15.5 >	15.5 >	0.044	0.007	2/5	N	
TF1.1 (PXT0603)	Patuxent	Oligohaline	0.91	12.0	3.1	3.050	0.105 >	3/4	N	
TF1.2 (WXT0045)	Patuxent	Oligohaline	•	6.0	2.7	0.464	0.023 >	2/3	N	
TF1.3 (PXT0494)	Patuxent	Oligohaline	•	11.5	5.9	2.852	0.057 >	2/3	N	
TF1.4 (PXT0456)	Patuxent	Oligohaline	3.63 >	25.5 >	18.8 >	2.14	0.05 >	0/4	N	
TF1.5 (PXT0402)	Patuxent	Oligohaline	4.83 >	48.0 >	46.0 >	0.794	0.03 >	0/4	N	
TF1.6 (XED9490)	Patuxent	Oligohaline	4.83 >	54.5 >	23.3 >	0.568	0.046 >	0/4	N	
TF1.7 (XED4892)	Patuxent	Oligohaline	2.9 >	29.0 >	6.9	0.458	0.054 >	1/4	N	
RET1.1(XDE9401)	Patuxent	Mesohaline	2.24 >	19.0 >	4.3	0.195 >	0.048 >	1/5	N	
LE1.1 (XDE5339)	Patuxent	Mesohaline	1.45	9.0	4.5	0.174 >	0.032 >	3/5	N	
LE1.2 (XDE2792)	Patuxent	Mesohaline	1.16	6.0	4.0	0.194 >	0.022 >	3/5	N	
LE1.3 (XDF0407)	Patuxent	Mesohaline	1.01	6.0	4.4	0.208 >	0.018 >	3/5	Y	Sparse SAV distribution
LE1.4 (XCF8747)	Patuxent	Mesohaline	0.91	6.0	8.1	0.144	0.012 >	4/5	N	Sparse SAV from Drum Pt. to Solomons
TF2.1 (XFB2470)	Potomac	Tidal Fresh	1.81	25.0 >	5.1	2.082	0.033 >	2/4	Y	High TSS median
TF2.2 (XFB1433)	Potomac	Tidal Fresh	2.42 >	25.0 >	8.4	2.015	0.032 >	1/4	Y	High TSS and Kd median
TF2.3 (XEA6596)	Potomac	Tidal Fresh	2.24 >	23.5 >	10.8	1.587	0.031 >	1/4	Y	High TSS and Kd median
MAT0078	Mattawoman	Tidal Fresh	•	8.5	1.2	0.139	0.038 >	2/3	N	
MAT0016	Mattawoman	Tidal Fresh	2.66 >	24.5 >	28.7 >	0.785	0.015	1/4	N	Sparse SAV along Cornwallis Neck
TF2.4 (XEA1840)	Potomac	Tidal Fresh	1.81	16.0 >	4.4	1.422	0.034 >	2/4	Y	
RET2.1 (XDA4238)	Potomac	Oligohaline	2.07 >	24.0 >	3.0	1.198	0.049 >	1/4	Y	Sparse SAV distribution
RET2.2 (XDA1177)	Potomac	Oligohaline	2.66 >	26.0 >	3.4	0.883	0.054 >	1/4	Y	
RET2.3 (XDB3321)	Potomac	Oligohaline	2.24 >	24.5 >	3.4	0.676	0.056 >	1/4	Y	
RET2.4 (XDC1706)	Potomac	Oligohaline	1.53	10.5	4.8	0.488	0.048 >	3/4	Y	

Table A-1. Continued

Station	Basin	Salinity	Kd	TSS	CHLA	DIN	DIP	HR Ratio	SAV	Comments
LE2.2	Potomac	Mesohaline	1.32	6.0	10.0	0.191 >	0.008	4/5	N	
LE2.3	Potomac	Mesohaline	0.73	4.4	9.4	0.053	0.004	5/5	N	
TF3.2	Rappahannock	Oligohaline	•	•	28.9 >	0.44	0.01	1/2	N	
TF3.3	Rappahannock	Oligohaline	3.63 >	•	5.3	0.55	0.01	2/3	N	
RET3.1	Rappahannock	Mesohaline	3.22 >	•	8.8	0.3 >	0.01	2/4	N	
RET3.2	Rappahannock	Mesohaline	2.42 >	•	13.8	0.23 >	0.01	2/4	N	
LE3.1	Rappahannock	Mesohaline	2.07 >	•	12.1	0.19 >	0.01	2/4	N	
LE3.2	Rappahannock	Mesohaline	1.07	•	9.7	0.14	0.01	4/4	N	
LE3.3	Rappahannock	Mesohaline	1.04	•	9.0	0.11	0.01	4/4	Y	Upriver limit of SAV in Rappahannock in 1987
LE3.4	Rappahannock	Mesohaline	1.04	•	8.7	0.12	0.01	4/4	Y	
LE3.6	Rappahannock	Mesohaline	0.88	6.5	9.2	0.041	0.01	5/5	Y	Very sparse SAV beds scattered along shoreline
LE3.7	Piankatank	Mesohaline	0.97	7.0	8.7	0.042	0.01	5/5	Y	Sparse SAV distribution
TF4.2	Mattaponi	Oligohaline	1.81	•	1.9	0.28	0.02	3/3	N	
TF4.4	Pamunkey	Oligohaline	1.45	•	1.3	0.21	0.03 >	2/3	N	
RET4.1	York	Mesohaline	4.14 >	•	6.2	0.29 >	0.02 >	1/4	N	
RET4.2	York	Mesohaline	3.63 >	•	2.6	0.185 >	0.02 >	1/4	N	
RET4.3	York	Mesohaline	3.42 >	•	13.2	0.22 >	0.02 >	1/4	N	
LE4.1	York	Polyhaline	2.42 >	•	23.7 >	0.18 >	0.01	1/4	N	
LE4.2	York	Polyhaline	1.71 >	•	14.2	0.13	0.015	3/4	N	
LE4.3	York	Polyhaline	1.07	•	12.6	0.145	0.01	4/4	Y	Upriver limit of SAV in the York River
TF5.2	James	Tidal Fresh	•	•	1.8	0.11	0.05 >	1/2	N	
TF5.3	James	Tidal Fresh	1.45	•	4.1	0.735	0.105 >	2/3	N	
TF5.4	James	Tidal Fresh	2.42 >	•	40.3 >	0.29	0.02	1/3	N	
TF5.5	James	Tidal Fresh	2.42 >	•	22.6 >	0.58	0.04 >	0/3	N	
TF5.6	James	Tidal Fresh	2.07 >	•	14.0	0.66	0.02	2/3	N	
RET5.1	James	Oligohaline	2.66 >	•	19.9 >	0.13	0.01	1/3	N	

Table A-1. Continued

Station	Basin	Salinity	Kd	TSS	CHLA	DIN	DIP	HR Ratio	SAV	Comments
RET5.2	James	Oligohaline	2.66 >	•	8.2	0.375	0.02	2/3	N	
LE5.1	James	Mesohaline	2.9 >	•	7.1	0.4 >	0.02 >	1/4	N	
LE5.2	James	Mesohaline	2.07 >	•	4.0	0.385 >	0.03 >	1/4	N	
LE5.3	James	Mesohaline	1.81 >	•	4.5	0.26 >	0.035 >	1/4	N	
LE5.4	James	Mesohaline	1.61 >	•	5.2	0.165 >	0.03 >	1/4	N	
LE5.6	James	•	•	•	•	•	•	•	•	Doesn't characterize existing/potential SAV habitat
LE5.5	James	Mesohaline	1.21	11.7	15.6 >	0.038	0.018 >	3/5	N	Southern shore not existing/potential SAV habitat

LEGEND:

>	=	SAV habitat requirement not met for preceding parameter
•	=	No data available or station does not characterize existing/potential SAV habitat
Kd	=	Light Attenuation Coefficient
TSS	=	Total Suspended Solids
CHLA	=	Chlorophyll a
DIN	=	Dissolved Inorganic Nitrogen
DIP	=	Dissolved Inorganic Phosphorus
(Stations)	=	Maryland Department of Environment station names

Appendix A — Table 2

Table A-2. Validation of the baywide application of SAV habitat requirements: 1989 SAV distribution and water quality conditions by monitoring program station.

Station	Basin	Salinity	Kd		TSS		CHLA		DIN		DIP		HR Ratio	SAV	Comments
CB1.1	Up. Mainstem	Tidal Fresh	1.63		10.9		8.6		1.423		0.009		4/4	Y	SAV decreased since 1987
CB2.1	Up. Mainstem	Oligohaline	3.27	>	20.0	>	6.6		1.184		0.011		2/4	N	
CB2.2	Up. Mainstem	Oligohaline	2.42	>	19.3	>	2.6		1.123		0.021	>	1/4	N	SAV present within Still Pond
CB3.1	Up. Mainstem	Mesohaline	1.81	>	10.6		4.5		1.118	>	0.019	>	2/5	N	
CB3.2	Up. Mainstem	Mesohaline	1.45		8.4		6.2		0.963	>	0.014	>	3/5	N	Sparse SAV in Swan Creek; along shoreline to Eastern Neck
CB3.3C	Up. Mainstem	•	•		•		•		•	•	•		•	•	Doesn't characterize existing/potential SAV habitat
CB3.3E	Up. Mainstem	Mesohaline	1.21		5.2		12.9		0.64	>	0.009		4/5	N	
CB3.3W	Up. Mainstem	Mesohaline	1.32		6.5		11.4		0.597	>	0.007		4/5	N	
CB4.1C	Up. Mainstem	•	•		•		•		•	•	•		•	•	Doesn't characterize existing/potential SAV habitat
CB4.1E	Up. Mainstem	Mesohaline	1.04		4.8		10.7		0.549	>	0.005		4/5	Y	DIN habitat goal exceeded
CB4.1W	Up. Mainstem	Mesohaline	1.45		8.9		17.9	>	0.46	>	0.006		3/5	N	
CB4.2C	Up. Mainstem	•	•		•		•		•	•	•		•	•	Doesn't characterize existing potential SAV habitat
CB4.2E	Up. Mainstem	Mesohaline	0.81		4.7		9.6		0.349	>	0.004		4/5	N	SAV present from Black Walnut Pt. north
CB4.2W	Up. Mainstem	•	•		•		•		•	•	•		•		Doesn't characterize existing/potential SAV habitat
CB4.3C	Up. Mainstem	•	•		•		•		•	•	•		•		Doesn't characterize existing/potential SAV habitat
CB4.3E	Up. Mainstem	Mesohaline	0.91		4.7		9.1		0.346	>	0.004		4/5	N	
CB4.3W	Up. Mainstem	•	•		•		•		•	•	•		•	•	Doesn't characterize existing/potential SAV habitat
CB4.4	Up. Mainstem	Mesohaline	0.81		4.6		9.1		0.341	>	0.005		4/5	N	Potential SAV habitat only on eastern shore
CB5.1	Up. Mainstem	Mesohaline	0.94		5.1		14.7		0.201	>	0.004		4/5	Y	SAV present along Barren Island; DIN habitat goal exceeded
CB5.2	Up. Mainstem	•	•		•		•		•	•	•		•	•	Doesn't characterize existing/potential SAV habitat
CB5.3	Up. Mainstem	•	•		•		•		•	•	•		•	•	Doesn't characterize existing/potential SAV habitat
CB5.4	L. Mainstem	Mesohaline	0.81		9.0		8.4		0.097		0.001		5/5	Y	
CB5.4W	L. Mainstem	Mesohaline	1.04		10.2		11.2		0.07		0.002		5/5	Y	Sparse SAV at mouth of Great Wicomico
CB5.5	L. Mainstem	Mesohaline	0.81		8.2		7.1		0.084		0.002		5/5	Y	

Table A-2. Continued

Station	Basin	Salinity	Kd	TSS	CHLA	DIN	DIP	HR Ratio	SAV	Comments
CB6.1	L. Mainstem	•	•	•	•	• •	•	•	•	Doesn't characterize existing/potential SAV habitat
CB6.2	L. Mainstem	Polyhaline	1.04	20.0 >	6.1	0.108	0.002	4/5	Y	Sparse SAV near Milford Haven + E. Shore; TSS HR exceeded
CB6.3	L. Mainstem	Polyhaline	0.97	18.0 >	5.8	0.114	0.003	4/5	N	Station characterizes W. Shore SAV habitat
CB6.4	L. Mainstem	•	•	•	•	• •	•	•	•	Doesn't characterize existing/potential habitat
CB7.1	L. Mainstem	Polyhaline	0.91	14.4	4.4	0.068	0.002	3/5	Y	
CB7.1N	L. Mainstem	Polyhaline	0.81	10.5	5.4	0.084	0.001	3/5	Y	
CB7.1S	L. Mainstem	Polyhaline	0.76	15.0	5.1	0.084	0.002	3/5	Y	Chlorophyll a habitat requirement exceeded
CB7.2	L. Mainstem	•	•	•	•	• •	•	•	•	Doesn't characterize existing/potential SAV habitat
CB7.2E	L. Mainstem	Polyhaline	0.91	13.6	5.5	0.092	0.002	5/5	Y	
CB7.3	L. Mainstem	Polyhaline	0.73	6.4	3.4	0.054	0.006	•	•	Doesn't characterize existing/potential SAV habitat
CB7.3E	L. Mainstem	Polyhaline	0.76	7.4	4.1	0.058	0.007	5/5	Y	
CB7.4	L. Mainstem	Polyhaline	0.81	5.7	3.9	0.023	0.01	•	•	Doesn't characterize existing/potential SAV habitat
CB7.4N	L. Mainstem	•	•	•	•	•	•	•	•	Doesn't characterize existing/potential SAV habitat
CB8.1	L. Mainstem	•	•	•	•	•	•	•	•	Doesn't characterize existing/potential SAV habitat
CB8.1E	L. Mainstem	•	•	•	•	•	•	•	•	Doesn't characterize existing/potential SAV habitat
EE1.1	Eastern Bay	Mesohaline	0.97	12.0	6.8	0.358 >	0.008	4/5	Y	DIN habitat goal exceeded
EE2.1	Choptank	Mesohaline	1.08	13.0	8.4	0.24 >	0.008	4/5	Y	DIN habitat goal exceeded
EE2.2	Little Choptank	Mesohaline	1.0	13.5	9.1	0.28 >	0.008	4/5	N	Very sparse SAV distribution in upper Little Choptank River
EE3.0	Honga	Mesohaline	2.42 >	34.0 >	13.5	0.048	0.004	3/5	N	
EE3.1	Tangier Sound	Mesohaline	1.61 >	23.5 >	9.1	0.161 >	0.004	2/5	N	SAV present along Bloodsworth Island
EE3.2	Tangier Sound	Mesohaline	0.86	15.5 >	5.6	0.136	0.008	4/5	Y	Abundant SAV distribution; TSS HR exceeded
EE3.3	Pocomoke Snd.	Mesohaline	1.33	22.0 >	11 .0	0.116	0.008	4/5	Y	SAV in lower Pocomoke Sound; TSS HR exceeded
EE3.4	Tangier Sound	Mesohaline	2.49 >	19.1 >	15.7 >	0.141	0.001	2/5	N	
EE3.5	Tangier Sound	Mesohaline	1.21	12.8	9.1	0.072	0.001	5/5	Y	
WE4.1	Mobjack Bay	Polyhaline	1.12	27.4 >	9.4	0.029	0.001	4/5	Y	Abundant SAV throughout Mobjack Bay; TSS HR exceeded
WE4.2	York River	Polyhaline	1.0	15.8 >	6.4	0.052	0.003	4/5	Y	Abundant SAV distribution; TSS HR exceeded

Table A-2. Continued

Station	Basin	Salinity	Kd		TSS		CHLA		DIN		DIP		HR Ratio	SAV	Comments
WE4.3	Poquoson	Polyhaline	0.97		22.0	>	6.6		0.027		0.001		4/5	Y	Abundant SAV distribution; TSS HR exceeded
WE4.4	Back	Polyhaline	1.12		31.6	>	4.9		0.032		0.002		4/5	Y	Abundant SAV distribution; TSS HRexceeded
ET1.1	Northeast	Oligohaline	3.63	>	18.0	>	50.0	>	0.417		0.004		1/4	N	
ET2.1	C&D Canal	•	•		•		•		•		•		•	•	Doesn't characterize existing/potential SAV habitat
ET2.2	Bohemia	Oligohaline	3.63	>	27.0	>	54.4	>	0.18		0.004		1/4	N	
ET2.3	Elk	Oligohaline	2.07	>	17.0	>	3.0		1.48		0.024	>	1/4	Y	Sparse SAV distribution
ET3.1	Sassafras	Oligohaline	4.83	>	21.5	>	85.6	>	0.27		0.006		1/4	N	
ET4.1	Chester	Mesohaline	7.25	>	40.0	>	15.0		1.952	>	0.042	>	1/5	N	
ET4.2	Chester	Mesohaline	1.26		11.0		3.8		0.513	>	0.01		4/5	Y	Sparse SAV distribution
ET5.1	Choptank	Mesohaline	4.83	>	21.5	>	10.8		1.972	>	0.04	>	1/5	N	
ET5.2	Choptank	Mesohaline	1.32		13.0		6.9		0.35	>	0.016	>	3/5	Y	Up river limit of SAV within the Choptank River
ET6.1	Nanticoke	Mesohaline	3.63	>	24.0	>	15.7	>	2.648	>	0.024	>	0/5	N	
ET6.2	Nanticoke	Mesohaline	4.83	>	32.0	>	11.8		0.606	>	0.004		2/5	N	
ET7.1	Wicomico	Mesohaline	3.63	>	31..0	>	13.5		0.486	>	0.01		2/5	N	
ET8.1	Manokin	Mesohaline	2.07	>	30.0	>	12.4		0.04		0.004		3/5	Y	
ET9.1	B. Annemessex	Mesohaline	1.45		21.0	>	9.6		0.032		0.004		4/5	Y	TSS habitat requirement exceeded
ET10.1	Pocomoke	Mesohaline	4.83	>	16.5	>	3.6		1.048	>	0.074	>	1/5	N	
WT1.1	Bush	Oligohaline	4.83	>	21.0	>	44.0	>	0.348		0.004		1/4	N	
WT2.1	Gunpowder	Oligohaline	3.63	>	24.0	>	28.5	>	0.313		0.005		1/4	N	
WT3.1	Middle	Oligohaline	2.9	>	19.0	>	26.2	>	0.238		0.006		1/4	N	
WT4.1	Back	Oligohaline	4.83	>	23.0	>	103.5	>	2.216		0.012		1/4	N	
WT5.1	Patapsco	Mesohaline	1.61	>	12.0		8.2		0.797	>	0.014	>	2/5	N	Upper Patapsco River not existing/potential SAV habitat
WT6.1	Magothy	Mesohaline	1.81	>	16.0	>	31.1	>	0.232	>	0.004		1/5	N	
WT7.1	Severn	Mesohaline	1.53	>	14.0		15.2	>	0.273	>	0.008		2/5	N	
WT8.1	South	Mesohaline	1.94	>	17.0	>	23.0	>	0.142		0.008		2/5	N	
WT8.2	Rhode	Mesohaline	2.42	>	20.0	>	39.4	>	0.04		0.007		2/5	N	
WT8.3	West	Mesohaline	2.07	>	20.5	>	34.6	>	0.121		0.006		2/5	N	

Table A-2. Continued

Station	Basin	Salinity	Kd	TSS	CHLA	DIN	DIP	HR Ratio	SAV	Comments
TF1.1	Patuxent	•	•	•	•	•	•	•	•	No data reported in 1989
TF1.2(WXT0045)	Patuxent	Oligohaline	•	8.0	3.0	0.536	0.029 >	2/3	N	
TF1.3(PXT0494)	Patuxent	Oligohaline	•	16.0 >	2.8	1.932	0.044 >	1/3	N	
TF1.4(PXT0456)	Patuxent	Oligohaline	3.63 >	21.0 >	6.2	2.024	0.046 >	1/4	N	
TF1.5(PXT0402)	Patuxent	Oligohaline	4.83 >	26.0 >	13.2	1.12	0.027 >	1/4	N	
TF1.6(XED9490)	Patuxent	Oligohaline	4.83 >	30.0 >	9.2	0.89	0.038 >	1/4	N	
TF1.7(XED4892)	Patuxent	Oligohaline	4.23 >	22.5 >	4.5	0.707	0.061 >	1/4	N	
RET1.1(XDE9401)	Patuxent	Mesohaline	2.9 >	26.0 >	8.3	0.292 >	0.031 >	1/5	N	
LE1.1(XDE5339)	Patuxent	Mesohaline	1.45	16.0 >	9.1	0.222 >	0.015 >	2/5	N	
LE1.2(XDE2792)	Patuxent	Mesohaline	1.04	17.0 >	6.9	0.25 >	0.01	3/5	N	
LE1.3(XDF0407)	Patuxent	Mesohaline	0.97	15.0	8.3	0.244 >	0.006	4/5	N	
LE1.4(XCF8747)	Patuxent	Mesohaline	0.91	13.0	8.2	0.306 >	0.006	4/5	N	
TF2.1(XFB2470)	Potomac	Tidal Fresh	2.9 >	20.0 >	5.7	2.092	0.038 >	1/4	Y	Only CHLA goal met
TF2.2(XFB1433)	Potomac	Tidal Fresh	2.66 >	21.0 >	6.6	2.048	0.038 >	1/4	Y	Only CHLA goal met
TF2.3(XEA6596)	Potomac	Tidal Fresh	2.24 >	16.0 >	7.5	1.996	0.028 >	1/4	Y	Only CHLA goal met
MAT0078	Mattawoman	Tidal Fresh		3.5	5.1	0.139	0.054 >	2/3	N	Missing Secchi depth and light attenuation data
MAT0016	Mattawoman	Tidal Fresh	4.23 >	22.5 >	51.5 >	0.554	0.015	1/4	Y	Sparse SAV along Cornwallis Neck; only DIP goal met
TF2.4(XEA1840)	Potomac	Tidal Fresh	1.81	13.0	3.8	1.948	0.032 >	3/4	Y	
RET2.1(DA4238)	Potomac	Oligohaline	2.42 >	19.5 >	3.0	1.836	0.048 >	1/4	Y	Sparse SAV distribution
RET2.2(XDA1177)	Potomac	Oligohaline	2.9 >	21.0 >	3.8	1.516	0.057 >	1/4	Y	
RET2.3(XDB3321)	Potomac	Oligohaline	2.66 >	23.0 >	4.0	1.228	0.058 >	1/4	Y	
RET2.4(XDC1706)	Potomac	Oligohaline	1.81	14.0	4.8	0.768	0.06 >	3/4	Y	
LE2.2	Potomac	Mesohaline	1.22	16.0 >	9.5	0.288 >	0.008	3/5	N	
LE2.3	Potomac	Mesohaline	0.91	5.2	12.9	0.119	0.004	5/5	N	
TF3.2	Rappahannock	Oligohaline	3.63 >	26.0 >	13.8	0.665	0.01	2/4	N	
TF3.3	Rappahannock	Oligohaline	3.63 >	42.0 >	12.1	0.18	0.01	2/4	N	

Table A-2. Continued

Station	Basin	Salinity	Kd	TSS	CHLA	DIN	DIP	HR Ratio	SAV	Comments
RET3.1	Rappahannock	Mesohaline	3.63	> 44.5	> 19.2	> 0.14	0.01	2/5	N	
RET3.2	Rappahannock	Mesohaline	2.66	> 20.5	> 12.9	0.13	0.01	3/5	N	
LE3.1	Rappahannock	Mesohaline	1.81	> 16.5	> 8.3	0.135	0.01	3/5	N	
LE3.2	Rappahannock	Mesohaline	0.91	8.5	7.4	0.12	0.01	5/5	Y	Upriver limit of SAV in the Rappahannock in 1989
LE3.3	Rappahannock	Mesohaline	0.85	6.0	10.9	0.09	0.01	5/5	Y	
LE3.4	Rappahannock	Mesohaline	0.76	6.5	6.6	0.135	0.01	5/5	Y	
LE3.6	Rappahnnock	Mesohaline	0.81	11.0	9.9	0.083	0.002	5/5	Y	Very sparse SAV beds scattered along shoreline
LE3.7	Piankatank	Mesohaline	0.92	9.4	9.9	0.019	0.001	5/5	Y	Sparse SAV distribution
TF4.2	Mattaponi	Oligohaline	2.42	> 12.0	1.5	0.38	0.02	3/4	N	
TF4.4	Pamunkey	Oligohaline	1.61	5.0	1.1	0.215	0.02	4/4	N	
RET4.1	York	Mesohaline	4.83	> 47.0	> 10.2	0.265	> 0.025	> 1/5	N	
RET4.2	York	Mesohaline	4.83	> 40.0	> 6.2	0.22	> 0.02	> 1/5	N	
RET4.3	York	Mesohaline	3.63	> 29.5	> 14.6	0.22	> 0.04	> 1/5	N	
LE4.1	York	Polyhaline	2.66	> 21.5	> 12.8	0.24	> 0.01	2/5	N	
LE4.2	York	Polyhaline	1.61	> 12.0	8.4	0.15	0.02	4/5	N	
LE4.3	York	Polyhaline	0.97	5.0	5.4	0.15	0.015	5/5	Y	Upriver limit of SAV in the York River in 1989
TF5.2	James	Tidal Fresh	•	9.5	1.6	0.38	0.075	> 2/3	N	
TF5.2A	James	Tidal Fresh	1.61	10.0	1.2	0.5	0.08	> 3/4	N	
TF5.3	James	Tidal Fresh	2.07	> 13.5	2.4	0.6	0.08	> 2/4	N	
TF5.4	James	Tidal Fresh	2.9	> 20.0	> 18.8	> 0.295	0.025	> 0/4	N	
TF5.5	James	Tidal Fresh	2.42	> 18.0	> 21.0	> 0.53	0.04	> 0/4	N	
TF5.5A	James	Tidal Fresh	2.9	> 26.5	> 30.0	> 0.69	0.05	> 0/4	N	
TF5.6	James	Tidal Fresh	2.42	> 20.0	> 16.0	> 0.66	0.04	> 0/4	N	
RET5.1	James	Oligohaline	•	•	•	•	• •	•	•	No data reported in 1989
RET5.1A	James	Oligohaline	2.42	> 18.5	> 22.9	> 0.105	0.01	1/4	N	
RET5.2	James	Oligohaline	3.63	> 34.5	> 17.6	> 0.5	0.02	1/4	N	
LE5.1	James	Mesohaline	3.63	> 41.0	> 12.1	0.47	> 0.03	> 1/5	N	

Table A-2. Continued

Station	Basin	Salinity	Kd		TSS		CHLA	DIN		DIP		HR Ratio	SAV	Comments
LE5.2	James	Mesohaline	2.42	>	18.0	>	5.0	0.405	>	0.045	>	1/5	N	
LE5.3	James	Mesohaline	1.94	>	11.0		6.0	0.39	>	0.045	>	3/5	N	
LE5.4	James	Mesohaline	1.32		9.5		4.1	0.31	>	0.045	>	3/5	N	
LE5.6	James	•	•		•		•	•	•	•		•	•	Doesn't characterize existing/potential SAV habitat
LE5.5	James	Mesohaline	1.12		7.2		8.7	0.213	>	0.018	>	3/5	N	S.shore not existing/potential SAV habitat

LEGEND:

>	=SAV habitat requirement not met for preceding parameter
•	=No data available or station does not characterize existing/potential SAV habitat
Kd	=Light Attenuation Coefficient
TSS	=Total Suspended Solids
CHLA	= Chlorophyll a
DIN	=Dissolved Inorganic Nitrogen
DIP	=Dissolved Inorganic Phosphorus
(Stations)	=Maryland Department of Environment station names

Appendix B—Table 1

Table B-1. Summary of analytical methods used in the sample analysis of data presented in the upper Potomac River case study and the nearshore/midchannel chapter.

All samples preserved by chilling; USGS nutrient samples were also preserved with mercuric chloride beginning in October 1980. MWCOG is the Metropolitan Washington Council of Governments Potomac Database; WATSTORE is the U.S. Geological Survey National Water Data Storage and Retrieval System; CBP code is the Chesapeake Bay Program Code; EPA is the U.S. EPA manual of methods, EPA-600/4-79-020; WY is water year (October through September); USGS is U.S. Geological Survey; USGSL is U.S. Geological Survey Atlanta Laboratory; USGSR is U.S.G.S. office in Reston, VA; DCRA is District of Columbia Department of Consumer and Regulatory Affairs; CRL is U.S. EPA Central Regional Laboratory; MDE is Maryland Department of the Environment; MDHMH is Maryland Department of Health and Mental Hygiene Laboratory; VSWCB is Virginia State Water Control Board; and, DCLS is Virginia Division of Consolidated Laboratories.

DISSOLVED AMMONIA (mg/l)
MWCOG code = NH3_N, WATSTORE code = 00608, CBP code = NH4

Agency	Method	Comments
USGS/USGSL (WY 1979-1981, 1983)	Skougstad *et al.*, 1979; I-2523-78 Colorimetric, Indophenol, Automated (Detection limit-0.01).	Filtered in the field. 0.45 micron filter.
DCRA/CRL (1983-1989)	EPA, 1983; #350.1-1-6 Colorimetric, Automated Phenate, AAII (Detection limit-0.04).	Filtered in the lab. Preserved with sulfuric acid.

TOTAL AMMONIA (mg/l)
MWCOG code = NH3_N, WATSTORE code = 00610, CBP code = NH4W

Agency	Method	Comments
USGS/USGSL (WY 1979-1981) (not in 1983)	Skougstad *et al.*, 1979; I-4523-78 (Detection limit-0.01).	Unfiltered.
MDE/MDHMH (1983-1989)	Am. Pub. Health Assoc., 1985; #417G, Automated Phenate, AAII (Detection limit-0.008 6/1/1986-1988; detection limit - 0.02 1983-5/31/1986).	Unfiltered. Samples with possible pH interferences are not adjusted before analysis.
VSWCB/DCLS (1983-1989)	EPA, 1979; #350.1-4-4 Colorimetric, Automated Phenate Technicon Auto Analyzer I (Detection limit - 0.1).	Unfiltered.

Note: Ammonia nitrogen—USGS method I-2523, EPA 350.1, and Standard Methods #417G are similar. The 0-5 mg/l range used by the USGS is wider than the 0-2 mg/l for EPA and Standard Methods. This will probably result in more scatter at lower concentrations.

NITRITE PLUS NITRATE (mg/l)

MWCOG stored NO2_N and NO3_N separately in the computer. For this parameter, NO3_N was added to NO2_N. WATSTORE code = 00631 (filtered) which was used if available. If not available, this parameter was calculated by adding 00613 (NO2_N) plus 00618 (NO3_N) (both filtered). CBP code = NO23.

Agency	Method	Comments
USGS/USGSL (WY 1979-1981, 1983)	NO23_N—Skougstad *et al.*, 1979; I-2545-78, Colorimetric, Cd Reduction, Automated (Detection limit-0.01).	Filtered in the field.
USGS/USGSL (WY 1979-1981, 1983)	NO2_N—Skougstad *et al.*, 1979; I-2540-78, Colorimetric, Diazotization, Automated, 1981 (00613) (Detection limit - .01).	Filtered in the field.
USGS/USGSL (WY 1983)	NO3_N—Skougstad *et al.*, 1979; Ion Chromatography (Detection limit - 0.01).	Filtered in the field.
DCRA/CRL (1983-1989)	EPA, 1983; #353.2-1-7 Colorimetric, Automated AAII (Detection limit-0.05).	Filtered in the lab. Preserved in the field with sulfuric acid.
MDE/MDHMH (1983-1989)	Am. Pub. Health Assoc., 1985; #418F, pp.400-402, Colorimetric, Automated, Technicon Auto Analyzer (Detection limit-0.02 for NO_3 and .002 for NO_2).	Unfiltered.
VSWCB/DCLS (1983-1989)	EPA, 1979; #353.2-1-7 Technicon Auto Analyzer I (Detection limit - 0.05).	Unfiltered.

Note: Nitrate is highly soluble, therefore, total and dissolved were considered to be equal; Nitrite nitrogen—USGS method I-2540 and EPA method 353.2 are similar in principle. It is not clearly stated in the EPA procedure what analytical range is recommended although it appears to be 0-10 mg/l. If this range is used, severe deterioration would occur for most nitrite values since they are typically low. The USGS range is 0-1.0 mg/l. Nitrate nitrogen—USGS method I-2545, EPA 353.2, and Standard Methods 418F are similar in principle and analytical ranges.

TOTAL KJELDAHL NITROGEN (mg/l)

MWCOG code = TKN, WATSTORE code = 00625, CBP code = TKNW

Agency	Method	Comments
USGS/USGSL (WY 1979-1981, 1983)	Skougstad *et al.*, 1979; I-4552-78, Block Digestion and Colorimetric, Automated (Detection limit-0.01).	Unfiltered.
DCRA/CRL (1983-1987)	EPA, 1983; #351.2 Colorimetric, Semi-automated Block Digestion AAII (Detection limit-0.1).	Unfiltered.
MDE/MDHMH (1983-1989)	EPA, 1979; #351.2 Colorimetric, Semi-automated Block Digestion, Technicon Technicon Auto Analyzer (Detection limit-0.1).	Unfiltered.
VSWCB/DCLS (1983-1989)	EPA, 1979; #351.2-1-5 Colorimetric, Semi-automated Block Digestion AAII (Detection limit - 0.1).	Unfiltered.

Note: Kjeldahl nitrogen—USGS method I-2552 and EPA method 351.2 are similar and should produce equivalent results; however, the analytical range (0-20 mg/l) is somewhat wider than the USGS (0-10 mg/l). This may cause more scatter at lower concentrations.

TOTAL NITROGEN (mg/l)

MWCOG code = calculated by adding TKN plus NO2 plus NO3,
WATSTORE code = calculated by adding 00625 to nitrite plus nitrate, CBP code = TN

Agency	Method	Comments
USGS/USGSL (WY 1979-1981, 1983)	See Total Kjeldahl and Total Nitrite plus Nitrate.	
DCRA/CRL (1983-1987)	See Total Kjeldahl and Dissolved Nitrite plus Nitrate.	
MDE/MDHMH (1983-1989)	See Total Kjeldahl and Total Nitrite plus Nitrate.	
VSWCB/DCLS (1983-1989)	See Total Kjeldahl and Total Nitrite plus Nitrate.	

TOTAL ORGANIC NITROGEN (mg/l)
MWCOG code = calculated by subtracting NH3_N from TKN,
WATSTORE code = calculated by subtracting 00610 from 00625, CBP code = TON

Agency	Method	Comments
USGS/USGSL	See Total Ammonia and Total Kjeldahl	
MDE/MDHMH	See Total Ammonia and Total Kjeldahl	
VSWCB/DCLS	See Total Ammonia and Total Kjeldahl	

TOTAL PHOSPHORUS (mg/l)
MWCOG code = TP, WATSTORE code = 00665, CBP code = TP

Agency	Method	Comments
USGS/USGSL (WY 1979-1981, 1983)	Skougstad *et al.*, 1979; I-4600-78 Colorimetric, Phosphomolybdate, Automated (Detection limit-0.001).	Unfiltered.
DCRA/CRL (1983-1987)	EPA, 1983; #365.1-1-9 Colorimetric, Automated, Ascorbic Acid, AAII (Detection limit - 0.01).	Unfiltered.
MDE/MDHMH (1983-1989)	EPA, 1979; #365.4-1-3 Semi-automated Block Digestion, Colorimetric, Ascorbic Acid Reduction, Technicon Auto Analyzer (Detection limit - 0.01).	Unfiltered.
VSWCB/DCLS (1983-1989)	EPA, 1979; #365.4-1-3 Colorimetric, Automated, Block Digestion AAII (Detection limit - 0.1).	Unfiltered.

Note: EPA methods 365.1 and 365.4 use different digestion procedures and the analytical range is much greater (0-20 mg/l vs 0-2 mg/l) than the USGS. The different digestion technique may or may not result in different values; however, the wide analytical range will certainly cause a deterioration in analytical results at lower concentrations.

DISSOLVED ORTHOPHOSPHATE (mg/l)
MWCOG code = OP, WATSTORE code = 00671, CBP code = P04F

Agency	Method	Comments
USGS/USGSL (1983)	Skougstad *et al.*, 1979; I-2601-78 Colorimetric, Phosphomolybdate, Automated (Detection limit -.001).	Filtered.
DCRA/CRL (1983-1988)	EPA, 1979; #365.1-1-9 Colorimetric, Ascorbic Acid, AAII (Dection limit - 0.007).	Filtered in the lab. Preserved with sulfuric acid.
MDE/MDHMH (1983-1989)	EPA, 1979; #365.1 Changed by 1985 to: Am. Pub. Health Assoc., 1985; #424G, p. 450-453. Automated, Colorimetric Ascorbic Acid Reduction, Technicon Auto Analyzer (Detection limit - 0.004 6/1/1986-1988; detection limit - 0.01 1983-5/31/1986).	Unfiltered.
VSWCB/DCLS (1983-1989)	EPA, 1979; #365.1-1-9 Technician Auto Analyzer I (Detection limit - 0.01).	Unfiltered.

Note: Orthophosphate—USGS method I-2601 and EPA method 365.1 are similar. The EPA method #365.1 (analytical range 0.01-1 mg/l) is better at lower concentrations than #424G (analytical range .001-10 mg/l).

TOTAL SOLUBLE PHOSPHORUS (mg/l)
MWCOG code = TSP, WATSTORE code = 00666, CBP code = TDP

Agency	Method	Comments
USGS/USGSL (WY1979, 1980, 1981, 1983)	Skougstad *et al.*, 1979; I-2600-78 (Detection limit - 0.001).	Filtered.
DCRA/CRL (1983-1987)	EPA, 1979; #365.1-1-9 Colorimetric, Automated, Ascorbic Acid.	Filtered.

TOTAL SUSPENDED SOLIDS (mg/l)
MWCOG code = TSS, WATSTORE code = 80154

Agency	Method	Comments
USGS/USGSL (WY 1979-1981 1983)	Skougstad *et al.*, 1979; I-3765-78 Residue dried at 105°C. Dried overnight (Detection limit - 1.0).	Sample is filtered through a glass fiber filter.
DCRA/CRL (1983-1988)	Am. Publ. Health Assoc., 1985; Residue dried at 103-105°C (Detection limit - 4.0).	
MDE/MDHMH (1983-1989)	Am. Publ. Health Assoc., 1985; #209C Residue dried at 103-105°C for 75-90 minutes (Detection limit - 1.0, 1983-88; detection limit - 0.8, 1989).	A well-mixed sample is filtered through Whatman 934-AH glass micro-fiber filter. Sample amount is subjective to amount of solid in sample.
VSWCB/DCLS (1983-1990)	Fishman and Friedman, 1989; I-3765-85.	

Note: Total suspended solids—The Standard Methods 208D or 209C-D and the USGS procedure (I-3765) are basically the same except for the drying times. The Standard Methods call for about an hour of drying time while the USGS procedure recommends drying overnight. Although the differences between results will probably be small, the USGS method may produce lower and more accurate results.

CORRECTED CHLOROPHYLL *a* (μg/l)
MWCOG code = CHLAM, WATSTORE code = 32211, 32209

Agency	Method	Comments
USGS/USGSR (WY 1979-1981, 1983)	Fluorometric method (Blanchard *et al.*, 1982) (Spectrophotometric method until the first week of the 1980 WY; detection limit - 0.2).	30-40 mls filtered through glass fibre filter. Filter preserved in 90% acetone, chilled, and kept dark.
DCRA/CRL (1983 -1988)	Am. Pub. Health Assoc., 1985; D3731-79, pp. 1079-1083 (Detection limit - 1.0).	In the absence of pheophytin, the trichromatic practice is used.
MDE/MDHMH (1983-1989)	Am. Pub. Health Assoc., 1985; 1002G-1 Spectrophotometric method pp. 1067-1070 (Beckman DU-6) (Detection limit - unavailable).	Millipore vacuum filtration system.
VSWCB (1983-1990)	EPA, 1973; (Monochromatic) pp. 14-16; Jeffrey and Humphrey, 1975; (Trichromatic) (Detection limit - unavailable).	Measured in mg/l, pheophytin measured at 665 nm after acidification. Trichromatic equation: Chla - 11.85 (OD664) - 1.54 (OD647) - 0.08 (OD630).

Note: Chlorophyll *a*—the trichromatic method (D 3731-79), the spectrophotometric methods (1002G-1), and the fluorometric method (USGS B6630) use different analytical approaches. There may not be good agreement between laboratories since this determination is quite technique dependent.

DISSOLVED INORGANIC PHOSPHORUS (mg/l)
MWCOG code = OP, WATSTORE code = 00666, CBP code = TDP, P04F

Agency	Method	Comments
USGS/USGSL (WY 1980-1981)	See Total Soluble Phosphorus	
DCECD/CRL (1983 -1988)	See Dissolved Orthophosphate	
MDE/MDHMH (1983-1989)	See Dissolved Orthophosphate	

DISSOLVED INORGANIC NITROGEN (mg/l)
MWCOG code = NH3_N plus NO2_N plus NO3_N, WATSTORE code = 00608 plus 00631 or 00608 plus 00618, CBP code = NH4 plus NO23 or NH4W plus NO23

Agency	Method	Comments
USGS/USGSL (WY 1980, 1981)	See Dissolved Ammonia and Nitrite plus Nitrate	
DCECD/CRL (1983-1988)	See Dissolved Ammonia and Nitrite plus Nitrate	
MDE/MDHMH (1983-1989)	See Total Ammonia and Nitrite plus Nitrate	

Appendix C — Table 1

Table C-1. References documenting historical and present Chesapeake Bay SAV species distribution by Chesapeake Bay Program Segment.

Segment CB1 — Northern Chesapeake Bay

Species	Reference
Ceratophyllum demersum	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stevenson and Confer, 1978; Aerial Survey Database 1987; Orth and Nowak, 1990.
Chara sp.	Bayley *et al.*, in press; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stevenson and Confer, 1978.
Elodea canadensis	Brush and Hilgartner, 1989; Bayley *et al.*, in press; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stevenson and Confer, 1978; Davis, 1985.
Heteranthera dubia	Orth *et al.*, 1986; Aerial Survey Database 1987; Orth and Nowak, 1990.
Hydrilla verticillata	Orth *et al.*, 1986; Aerial Survey Database 1987; Orth and Nowak, 1990.
Myriophyllum spicatum	Brush and Hilgartner, 1989; Bayley *et al.*, in press; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stevenson and Confer, 1978; Davis, 1985; Aerial Survey Database 1987; Orth and Nowak, 1990.
Najas sp.	Bayley *et al.*, in press; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stevenson and Confer, 1978; Aerial Survey Database 1987.
Najas flexilis	Brush and Davis, 1984; Brush and Hilgartner, 1989; Davis, 1985.
Najas gracillima	Davis, 1985.
Najas guadalupensis	Brush and Hilgartner, 1989; Davis, 1985; Aerial Survey Database 1987; Orth and Nowak, 1990.
Najas minor	Davis, 1985.
Potamogeton amplifolius	Springer *et al.*, 1958; Stevenson and Confer, 1978.
Potamogeton gramineus	Springer *et al.*, 1958; Stevenson and Confer, 1978.

Segment CB1 — Northern Chesapeake Bay (Continued)

Species	Reference
Potamogeton nodosus	Springer *et al.*, 1958; Stevenson and Confer, 1978.
Potamogeton diversifolius	Brush and Davis, 1984; Davis, 1985; Brush and Hilgartner, 1989.
Potamogeton epihydrus	Brush and Davis, 1984; Davis, 1985; Brush and Hilgartner, 1989.
Potamogeton pectinatus	Bayley *et al.*, in press; Stevenson and Confer, 1978; Orth *et al.*, 1986; Aerial Survey Database 1987; Orth and Nowak, 1990.
Potamogeton perfoliatus	Bayley *et al.*, in press; Stevenson and Confer, 1978; Aerial Survey Database 1987; Orth and Nowak, 1990.
Vallisneria americana	Brush and Hilgartner, 1989; Bayley *et al.*, in press; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stevenson and Confer, 1978; Davis, 1985; Aerial Survey Database 1987; Orth and Nowak, 1990.
Zannichellia palustris	Brush and Hilgartner, 1989.

Segment CB2 — Upper Chesapeake Bay

Species	Reference
Ceratophyllum demersum	Stevenson and Confer, 1978; Aerial Survey Database 1987; Orth and Nowak, 1990.
Chara sp.	Stotts, 1970; Stevenson and Confer, 1978.
Elodea canadensis	Stotts, 1970; Stevenson and Confer, 1978; Orth and Nowak, 1990.
Heteranthera dubia	Aerial Survey Database 1987.
Hydrilla vericillata	Orth and Nowak, 1990.
Myriophyllum spicatum	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro 1976a; Munro 1976b; Stotts, 1960; Stotts, 1970; Stevenson and Confer, 1978; Aerial Survey Database 1987; Orth and Nowak, 1990.
Najas sp.	Stotts 1960; Stotts, 1970; Stevenson and Confer, 1978.
Najas guadalupensis	Aerial Survey Database 1987.
Potamogeton crispus	Orth and Nowak, 1990.
Potamogeton pectinatus	Stevenson and Confer, 1978; Orth and Nowak, 1990.
Potamogeton perfoliatus	Stotts, 1970; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986.

Segment CB2 — Upper Chesapeake Bay (Continued)

Species	Reference
Ruppia maritima	Stotts, 1970; Stevenson and Confer, 1978; Orth and Nowak, 1990.
Vallisneria americana	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1960; Stotts, 1970; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Aerial Survey Database 1987; Orth and Nowak, 1990.
Zannichellia palustris	Stevenson and Confer, 1978; Orth and Nowak, 1990.

Segment CB3 — Upper Central Chesapeake Bay

Species	Reference
Ceratophyllum demersum	Stotts, 1960; Stevenson and Confer, 1978; Orth and Nowak, 1990.
Chara sp.	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1970; Stevenson and Confer, 1978.
Elodea canadensis	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1960; Stotts, 1970; Stevenson and Confer, 1978; Aerial Survey Database 1987; Orth and Nowak, 1990.
Hydrilla verticillata	Orth and Nowak, 1990.
Myriophyllum spicatum	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1960; Stotts, 1970; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Aerial Survey Database 1987; Orth and Nowak, 1990.
Najas sp.	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1960; Stotts, 1970; Stevenson and Confer, 1978.
Najas guadalupensis	Maryland Department of Natural Resources Ground Survey, 1971-1986; Aerial Survey Database 1987.
Potamogeton crispus	Orth and Nowak, 1990.
Potamogeton pectinatus	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro 1976a; Munro, 1976b; Stotts, 1960; Stotts, 1970; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Aerial Survey Database 1987; Orth and Nowak, 1990.
Potamogeton perfoliatus	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro 1976a; Munro, 1976b; Stotts, 1960; Stotts, 1970; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Aerial Survey Database 1987; Orth and Nowak, 1990.

Segment CB3 — Upper Central Chesapeake Bay (Continued)

Species	Reference
Ruppia maritima	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1960; Stotts, 1970; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Aerial Survey Database 1987; Orth and Nowak, 1990.
Vallisneria americana	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1960; Stotts, 1970; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Aerial Survey Database 1987; Orth and Nowak, 1990.
Zannichellia palustris	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1970; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Aerial Survey Database 1987; Orth and Nowak, 1990.
Zostera marina	Stotts, 1970; Stevenson and Confer, 1978.

Segment CB4 — Middle Central Chesapeake Bay

Species	Reference
Ceratopyllum demersum	Orth and Nowak, 1990.
Elodea canadensis	Aerial Survey Database 1987; Orth and Nowak, 1990.
Myriophyllum spicatum	Orth and Nowak, 1990.
Potamogeton pectinatus	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stewart, 1962; Stotts, 1970; Stevenson and Confer, 1978; Aerial Survey Database 1987; Orth and Nowak, 1990.
Potamogeton perfoliatus	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1960; Stotts, 1970; Stevenson and Confer, 1978; Aerial Survey Database 1987; Orth and Nowak, 1990.
Ruppia maritima	Elser, 1969; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1960; Stotts, 1970; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Aerial Survey Database 1987; Orth and Nowak, 1990.
Vallisneria americana	Stevenson and Confer, 1978.
Zannichellia palustris	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Aerial Survey Database 1987; Orth and Nowak, 1990.

Segment CB4 — Middle Central Chesapeake Bay (Continued)

Species	Reference
Zostera marina	Elser, 1969; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1960; Stotts, 1970; Stevenson and Confer, 1978.

Segment CB5 — Lower Chesapeake Bay

Species	Reference
Potamogeton pectinatus	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stewart, 1962; Stotts, 1970; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986.
Ruppia maritima	Elser, 1969; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1960; Stotts, 1970; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Aerial Survey Database 1987; Orth *et al.*, 1979; Orth and Nowak, 1990.
Zannichellia palustris	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Aerial Survey Database 1987.
Zostera marina	Elser, 1969; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a, Munro, 1976b; Stotts, 1960; Stotts, 1970; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Aerial Survey Database 1987; Orth *et al.*, 1979; Orth and Nowak, 1990.

Segment CB6 — Western Lower Chesapeake Bay

Species	Reference
Ruppia maritima	Aerial Survey Database 1987; Orth and Nowak, 1990.
Zostera marina	Aerial Survey Database 1987; Orth and Nowak, 1990.

Segment CB7 — Eastern Lower Chesapeake Bay

Species	Reference
Potamogeton pectinatus	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stevenson and Confer, 1978.
Ruppia maritima	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stevenson and Confer, 1978; Aerial Survey Database 1987; Orth *et al.*, 1979; Orth and Nowak, 1990.

Segment CB7 — Eastern Lower Chesapeake Bay (Continued)

Species	Reference
Zostera marina	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stevenson and Confer, 1978; Aerial Survey Database 1987; Orth *et al.*, 1979; Orth and Nowak, 1990.
Zannichellia palustris	Aerial Survey Database 1987; Orth *et al.*, 1979.

Segment CB8 — Mouth of Chesapeake Bay

Species	Reference
Ruppia maritima	Aerial Survey Database 1987; Orth and Nowak, 1990.
Zostera marina	Aerial Survey Database 1987; Orth and Nowak, 1990.

Segment WT1 — Bush River

Species	Reference
Ceratophyllum demersum	Elser, 1969; Stevenson and Confer, 1978; Orth and Nowak, 1990.
Chara sp.	Stevenson and Confer, 1978.
Elodea canadensis	Stevenson and Confer, 1978; Orth and Nowak, 1990.
Myriophyllum spicatum	Elser, 1969; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro 1976a; Munro, 1976b; Stevenson and Confer, 1978; Aerial Survey Database 1987; Orth and Nowak, 1990.
Najas sp.	Stevenson and Confer, 1978.
Potamogeton pectinatus	Stevenson and Confer, 1978; Orth and Nowak, 1990.
Potamogeton perfoliatus	Stevenson and Confer, 1978.
Ruppia maritima	Stevenson and Confer, 1978.
Vallisneria americana	Elser, 1969; Stevenson and Confer, 1978; Aerial Survey Database 1987.
Zannichellia palustris	Stevenson and Confer, 1978; Orth and Nowak, 1990.

Segment WT2 — Gunpowder River

Species	Reference
Ceratophyllum demersum	Elser, 1969; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stevenson and Confer, 1978; Orth and Nowak, 1990.
Chara sp.	Stevenson and Confer, 1978.
Elodea canadensis	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stevenson and Confer, 1978; Orth and Nowak, 1990.
Myriophyllum spicatum	Elser, 1969; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a, Munro, 1976b; Stotts, 1960; Stevenson and Confer, 1978; Southwick, 1967-1969; Maryland Department of Natural Resources Ground Survey, 1971-1986; Aerial Survey Database 1987; Orth and Nowak, 1990.
Najas sp.	Stotts, 1960; Stevenson and Confer, 1978.
Najas guadalupensis	Brush and Hilgartner, 1989.
Najas gracillima	Brush and Hilgartner, 1989.
Potamogeton pectinatus	Stevenson and Confer, 1978; Orth and Nowak, 1990.
Potamogeton perfoliatus	Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986.
Ruppia maritima	Brush and Hilgartner, 1989; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stevenson and Confer, 1978.
Vallisneria americana	Brush and Hilgartner, 1989; Elser, 1969; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1960; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Aerial Survey Database 1987.
Zannichellia palustris	Brush and Hilgartner, 1989; Stevenson and Confer, 1978; Orth and Nowak, 1990.

Segment WT3 — Middle River

Species	Reference
Ceratophyllum demersum	Stevenson and Confer, 1978; Aerial Survey Database 1987; Orth and Nowak, 1990.
Chara sp.	Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986.

Segment WT3 — Middle River (Continued)

Species	Reference
Elodea canadensis	Brush and Hilgartner, 1989; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Aerial Survey Database 1987; Orth and Nowak, 1990.
Myriophyllum spicatum	Brush and Hilgartner, 1989; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1960; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Aerial Survey Database 1987; Orth and Nowak, 1990.
Najas sp.	Stotts, 1960; Stevenson and Confer, 1978.
Najas guadalupensis	Brush and Hilgartner, 1989; Maryland Department of Natural Resources Ground Survey, 1971-1986.
Najas gracillimas	Brush and Hilgartner, 1989.
Potamogeton crispus	Maryland Department of Natural Resources Ground Survey, 1971-1986.
Potamogeton pectinatus	Stevenson and Confer, 1978; Aerial Survey Database 1987; Orth and Nowak, 1990.
Potamogeton perfoliatus	Brush and Hilgartner, 1989; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986.
Ruppia maritima	Brush and Hilgartner, 1989; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986.
Vallisneria americana	Brush and Hilgartner, 1989; Stotts, 1960; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Aerial Survey Database 1987.
Zannichellia palustris	Brush and Hilgartner, 1989; Stevenson and Confer, 1978; Orth and Nowak, 1990.

Segment WT4 — Back River

Species	Reference
Ceratophyllum demersum	Stevenson and Confer, 1978; Aerial Survey Database 1987; Orth and Nowak, 1990.
Chara sp.	Stevenson and Confer, 1978.

Segment WT4 — Back River (Continued)

Species	Reference
Elodea canadensis	Brush and Hilgartner, 1989; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stevenson and Confer, 1978; Aerial Survey Database 1987; Orth and Nowak, 1990.
Myriophyllum spicatum	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1960; Stevenson and Confer, 1978; Southwick, 1967-1969; Aerial Survey Database 1987; Orth and Nowak, 1990.
Najas sp.	Stotts, 1960; Stevenson and Confer, 1978.
Najas guadalupensis	Brush and Hilgartner, 1989.
Najas gracillima	Brush and Hilgartner, 1989.
Potamogeton pectinatus	Stevenson and Confer, 1978; Aerial Survey Database 1987; Orth and Nowak, 1990.
Potamogeton perfoliatus	Stevenson and Confer, 1978.
Ruppia maritima	Brush and Hilgartner, 1989; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stevenson and Confer, 1978.
Vallisneria americana	Brush and Hilgartner, 1989; Stotts, 1960; Stevenson and Confer, 1978; Aerial Survey Database 1987.
Zannichellia palustris	Brush and Hilgartner, 1989; Stevenson and Confer, 1978; Orth and Nowak, 1990.

Segment WT5 — Patapsco River

Species	Reference
Ceratophyllum demersum	Orth and Nowak, 1990.
Elodea canadensis	Stevenson and Confer, 1978; Orth and Nowak, 1990.
Myriophyllum spicatum	Stevenson and Confer, 1978; Orth and Nowak, 1990.
Najas sp.	Stevenson and Confer, 1978.
Najas guadalupensis	Brush and Hilgartner, 1989.
Potamogeton pectinatus	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Orth and Nowak, 1990.

Segment WT5 — Patapsco River (Continued)

Species	Reference
Potamogeton perfoliatus	Brush and Hilgartner, 1989; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986.
Ruppia maritima	Brush and Hilgartner, 1989; Stevenson and Confer, 1978.
Vallisneria americana	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986.
Zannichellia palustris	Brush and Hilgartner, 1989; Maryland Department of Natural Resources Ground Survey, 1971-1986; Aerial Survey Database 1987; Orth and Nowak, 1990.

Segment WT6 — Magothy River

Species	Reference
Ceratophyllum demersum	Stevenson and Confer, 1978; Orth and Nowak, 1990.
Chara sp.	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1970; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986.
Elodea canadensis	Stevenson and Confer, 1978; Aerial Survey Database 1987; Orth and Nowak, 1990.
Myriophyllum spicatum	Elser, 1969; Stevenson and Confer, 1978; Personal communication from Younger, Consulting Biologists, Inc. to Roach, 1963; Orth and Nowak, 1990.
Najas sp.	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1970; Stevenson and Confer, 1978.
Najas guadalupensis	Maryland Department of Natural Resources Ground Survey, 1971-1986.
Potamogeton pectinatus	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1960; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Aerial Survey Database 1987; Personal communication from Younger, Consulting Biologists, Inc. to Roach, 1963; Orth and Nowak, 1990.
Potamogeton perfoliatus	Elser, 1969; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1960; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Aerial Survey Database 1987; Personal communication from Younger, Consulting Biologists, Inc. to Roach, 1963.

Segment WT6 — Magothy River (Continued)

Species	Reference
Ruppia maritima	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1960; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986.
Vallisneria americana	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1970; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986.
Zannichellia palustris	Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Aerial Survey Database 1987; Orth and Nowak, 1990.

Segment WT7 — Severn River

Species	Reference
Ceratophyllum demersum	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stevenson and Confer, 1978.
Chara sp.	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986.
Elodea canadensis	Brush and Hilgartner, 1989; Elser, 1969; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Phillip and Brown, 1965; Southwick and Pine, 1975; Stevenson and Confer, 1978; Aerial Survey Database 1987.
Myriophyllum spicatum	Elser, 1969; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Phillip and Brown, 1965; Southwick and Pine, 1975; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986.
Najas sp.	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stevenson and Confer, 1978.
Najas guadalupensis	Brush and Hilgartner, 1989; Maryland Department of Natural Resources Ground Survey, 1971-1986.
Potamogeton pectinatus	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Phillip and Brown, 1965; Southwick and Pine, 1975; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Aerial Survey Database 1987; Orth and Nowak, 1990.
Potamogeton perfoliatus	Brush and Hilgartner, 1989; Elser, 1969; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986.

Segment WT7 — Severn River (Continued)

Species	Reference
Ruppia maritima	Brush and Hilgartner, 1989; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Orth and Nowak, 1990.
Vallisneria americana	Brush and Hilgartner, 1989; Stevenson and Confer, 1978.
Zannichellia palustris	Brush and Hilgartner, 1989; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Southwick and Pine, 1975; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Aerial Survey Database 1987; Orth and Nowak, 1990.

Segment WT8 — South, Rhode, and West Rivers

Species	Reference
Elodea canadensis	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Phillip and Brown, 1965; Southwick and Pine, 1975; Stevenson and Confer, 1978.
Myriophyllum spicatum	Elser, 1969; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stevenson and Confer, 1978; Phillip and Brown, 1965; Southwick and Pine, 1975.
Potamogeton pectinatus	Elser, 1969; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stevenson and Confer, 1978; Phillip and Brown, 1965; Southwick and Pine, 1975; Orth and Nowak, 1990.
Potamogeton perfoliatus	Elser, 1969; Stevenson and Confer, 1978; Phillip and Brown, 1965; Southwick and Pine, 1975.
Ruppia maritima	Elser, 1969; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stevenson and Confer, 1978; Phillip and Brown, 1965; Southwick and Pine, 1975; Maryland Department of Natural Resources Ground Survey, 1971-1986; Aerial Survey Database 1987; Orth and Nowak, 1990.
Vallisneria americana	Stevenson and Confer, 1978.
Zannichellia palustris	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stevenson and Confer, 1978; Phillip and Brown, 1965; Southwick and Pine, 1975; Aerial Survey Database 1987; Orth and Nowak, 1990.

Segment TF1 — Upper Patuxent River

Species	Reference
Ceratopyllum demersum	Orth and Nowak, 1990.
Elodea canadensis	Stevenson and Confer, 1978; Orth and Nowak, 1990.
Najas sp.	Stevenson and Confer, 1978; Orth and Nowak, 1990.
Najas flexilis	Brush and Davis, 1984; Davis, 1985; Brush and Hilgartner, 1989.
Najas guadalupensis	Brush and Hilgartner, 1989; Orth and Nowak, 1990.
Potamogeton crispus	Orth and Nowak, 1990.
Potamogeton diversifolius	Brush and Davis, 1984; Davis, 1985; Brush and Hilgartner, 1989.
Potamogeton epihydrus	Brush and Davis, 1984; Davis, 1985; Brush and Hilgartner, 1989.
Potamogeton pectinatus	Stevenson and Confer, 1978; Aerial Survey Database 1987; Orth and Nowak, 1990.
Potamogeton perfoliatus	Anderson *et al.*, 1967; Stevenson and Confer, 1978.
Potamogeton pusillus	Orth and Nowak, 1990.
Ruppia maritima	Anderson *et al.*, 1967; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stevenson and Confer, 1978.
Vallisneria americana	Stevenson and Confer, 1978; Orth and Nowak, 1990.
Zannichellia palustris	Brush and Hilgartner, 1989; Stevenson and Confer, 1978.
Zostera marina	Elser, 1969; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1960; Stevenson and Confer, 1978.

Segment RET1 — Middle Patuxent River

Species	Reference
Ceratophyllum demersum	Maryland Department of Natural Resources Ground Survey, 1971-1986; Orth and Nowak, 1990.
Chara sp.	Maryland Department of Natural Resources Ground Survey, 1971-1986.
Elodea canadensis	Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Orth and Nowak, 1990.
Myriophyllum spicatum	Maryland Department of Natural Resources Ground Survey, 1971-1986; Aerial Survey Database 1987.

Segment RET1 — Middle Patuxent River (Continued)

Species	Reference
Najas sp.	Stevenson and Confer, 1978; Orth and Nowak, 1990.
Najas flexilis	Brush and Davis, 1984; Davis, 1985; Brush and Hilgartner, 1989.
Najas guadalupensis	Brush and Hilgartner, 1989; Maryland Department of Natural Resources Ground Survey, 1971-1986; Orth and Nowak, 1990.
Potamogeton crispus	Maryland Department of Natural Resources Ground Survey, 1971-1986; Orth and Nowak, 1990.
Potamogeton diversifolius	Brush and Davis, 1984; Davis, 1985; Brush and Hilgartner, 1989.
Potamogeton epihydrus	Brush and Davis, 1984; Davis, 1985; Brush and Hilgartner, 1989.
Potamogeton pectinatus	Stevenson and Confer, 1978; Aerial Survey Database 1987; Orth and Nowak, 1990.
Potamogeton perfoliatus	Anderson *et al.*, 1969; Stevenson and Confer, 1978.
Potamogeton pusillus	Orth and Nowak, 1990.
Ruppia maritima	Anderson *et al.*, 1969; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stevenson and Confer, 1978; Aerial Survey Database 1987.
Vallisneria americana	Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Orth and Nowak, 1990.
Zannichellia palustris	Brush and Hilgartner, 1989; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Aerial Survey Database 1987.
Zostera marina	Elser, 1969; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1960; Stevenson and Confer, 1978.

Segment LE1 —Lower Patuxent River

Species	Reference
Elodea canadensis	Stevenson and Confer, 1978.
Myriophyllum spicatum	Maryland Department of Natural Resources Ground Survey, 1971-1986; Orth and Nowak, 1990.
Najas sp.	Stevenson and Confer, 1978.

Segment LE1 —Lower Patuxent River (Continued)

Species	Reference
Potamogeton pectinatus	Stevenson and Confer, 1978; Aerial Survey Database 1987; Orth and Nowak, 1990.
Potamogeton perfoliatus	Anderson *et al.*, 1969; Stevenson and Confer, 1978.
Ruppia maritima	Anderson *et al.*, 1969; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Aerial Survey Database 1987; Orth and Nowak, 1990.
Vallisneria americana	Stevenson and Confer, 1978.
Zannichellia palustris	Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Aerial Survey Database 1987; Orth and Nowak, 1990.
Zostera marina	Elser, 1969; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1960; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986.

Segment TF2 — Upper Potomac River

Species	Reference
Ceratophyllum demersum	Carter *et al.*, 1985a; Carter *et al.*, 1985b; Paschal *et al.*, 1982; Rybicki *et al.*, 1986; Stevenson and Confer, 1978; Aerial Survey Database 1987; Orth and Nowak, 1990.
Chara sp.	Rybicki *et al.*, 1987.
Egeria densa	Paschal *et al.*, 1982.
Elodea canadensis	Stevenson and Confer, 1978.
Heteranthera dubia	Carter *et al.*, 1985a; Carter *et al.*, 1985b; Rybicki *et al.*, 1987; Aerial Survey Database 1987; Orth and Nowak, 1990.
Hydrilla verticillata	Carter *et al.*, 1985a; Carter *et al.*, 1985b; Rybicki *et al.*, 1986; Rybicki *et al.*, 1987; Aerial Survey Database 1987; Orth and Nowak, 1990.
Myriophyllum spicatum	Carter *et al.*, 1985a; Carter *et al.*, 1985b; Rybicki *et al.*, 1986; Rybicki *et al.*, 1987; Stevenson and Confer, 1978; Aerial Survey Database 1987; Orth and Nowak, 1990.
Najas sp.	Stewart, 1962; Stevenson and Confer, 1978; Aerial Survey Database 1987.
Najas minor	Rybicki *et al.*, 1987; Orth and Nowak, 1990.

Segment TF2 — Upper Potomac River (Continued)

Species	Reference
Najas guadalupensis	Carter *et al.*, 1985a; Carter *et al.*, 1985b; Rybicki *et al.*, 1986; Rybicki *et al.*, 1987; Orth and Nowak, 1990.
Najas gracillima	Aerial Survey Database 1987.
Nitella flexilis	Carter *et al.*, 1985a; Carter *et al.*, 1985b; Rybicki *et al.*, 1986; Rybicki *et al.*, 1987.
Potamogeton crispus	Carter *et al.*, 1985a; Carter *et al.*, 1985b.
Potamogeton pectinatus	Carter *et al.*, 1985a; Carter *et al.*, 1985b; Rybicki *et al.*, 1986. Rybicki *et al.*, 1987; Stewart, 1962; Stevenson and Confer, 1978; Orth and Nowak, 1990.
Potamogeton perfoliatus	Stevenson and Confer, 1978.
Potamogeton pusillus	Paschal *et al.*, 1982; Rybicki *et al.*, 1987; Orth and Nowak, 1990.
Ruppia maritima	Stevenson and Confer, 1978.
Vallisneria americana	Carter *et al.*, 1985a; Carter *et al.*, 1985b; Paschal *et al.*, 1982; Rybicki *et al.*, 1987; Stewart, 1962; Stevenson and Confer, 1978; Aerial Survey Database 1987; Orth and Nowak, 1990.
Zannichellia palustris	Carter *et al.*, 1985a; Carter *et al.*, 1985b; Rybicki *et al.*, 1986; Rybicki *et al.*, 1987; Aerial Survey Database 1987.

Segment RET2 — Middle Potomac River

Species	Reference
Ceratophyllum demersum	Carter *et al.*, 1985a; Carter *et al.*, 1985b; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stevenson and Confer, 1978; Paschal *et al.*, 1982; Rybicki *et al.*, 1988; Orth and Nowak, 1990.
Chara sp.	Paschal *et al.*, 1982.
Elodea canadensis	Paschal *et al.*, 1982; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stevenson and Confer, 1978; Aerial Survey Database 1987.
Heteranthera dubia	Rybicki *et al.*, 1988.
Hydrilla verticillata	Rybicki *et al.*, 1988.

Segment RET2 — Middle Potomac River (Continued)

Species	Reference
Myriophyllum spicatum	Carter *et al.*, 1985a; Carter *et al.*, 1985b; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Paschal *et al.*, 1982; Stevenson and Confer, 1978; Rybicki *et al.*, 1988; Orth and Nowak, 1990.
Najas sp.	Paschal *et al.*, 1982; Stevenson and Confer, 1978; Orth and Nowak, 1990.
Najas guadalupensis	Carter *et al.*, 1985a; Carter *et al.*, 1985b; Aerial Survey Database 1987.
Najas minor	Rybicki *et al.*, 1988.
Potamogeton crispus	Paschal *et al.*, 1982; Rybicki *et al.*, 1987; Aerial Survey Database 1987; Orth *et al.*, 1979; Orth and Nowak, 1990.
Potamogeton pectinatus	Carter *et al.*, 1985a; Carter *et al.*, 1985b; Paschal *et al.*, 1982; Stevenson and Confer, 1978; Rybicki *et al.*, 1988; Orth and Nowak, 1990.
Potamogeton perfoliatus	Carter *et al.*, 1985a; Carter *et al.*, 1985b; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Paschal *et al.*, 1982; Stevenson and Confer, 1978; Orth *et al.*, 1979; Rybicki *et al.*, 1988; Orth and Nowak, 1990.
Potamogeton pusillus	Carter *et al.*, 1985a; Carter *et al.*, 1985b; Aerial Survey Database 1987; Orth and Nowak, 1990.
Ruppia maritima	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Paschal *et al.*, 1982; Stevenson and Confer, 1978; Aerial Survey Database 1987; Orth and Nowak, 1990.
Vallisneria americana	Carter *et al.*, 1985a; Carter *et al.*, 1985b; Paschal *et al.*, 1982; Rybicki *et al.*, 1986; Rybicki *et al.*, 1988; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro 1976a; Munro, 1976b; Stevenson and Confer, 1978; Orth *et al.*, 1979; Orth and Nowak, 1990.
Zannichellia palustris	Carter *et al.*, 1985a; Carter *et al.*, 1985b; Paschal *et al.*, 1982; Rybicki *et al.*, 1987; Aerial Survey Database 1987; Orth *et al.*, 1979.

Segment LE2 — Lower Potomac River

Species	Reference
Chara sp.	Paschal *et al.*, 1982.
Elodea canadensis	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Paschal *et al.*, 1982; Stevenson and Confer, 1978; Orth and Nowak, 1990.
Myriophyllum spicatum	Paschal *et al.*, 1982; Rybicki *et al.*, 1987; Stevenson and Confer, 1978.

Segment LE2 — Lower Potomac River (Continued)

Species	Reference
Najas sp.	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Paschal *et al.*, 1982; Stevenson and Confer, 1978.
Najas guadalupensis	Carter *et al.*, 1985a; Carter *et al.*, 1985b.
Potamogeton crispus	Paschal *et al.*, 1982.
Potamogeton pectinatus	Paschal *et al.*, 1982; Stevenson and Confer, 1978.
Potamogeton perfoliatus	Carter *et al.*, 1985a; Carter *et al.*, 1985b; Rybicki *et al.*, 1987; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Paschal *et al.*, 1982; Stevenson and Confer, 1978; Aerial Survey Database 1987; Orth and Nowak, 1990.
Potamogeton pusillus	Paschal *et al.*, 1982.
Ruppia maritima	Carter *et al.*, 1985a; Carter *et al.*, 1985b; Paschal *et al.*, 1982; Rybicki *et al.*, 1987; Stevenson and Confer, 1978; Aerial Survey Database 1987; Orth and Nowak, 1990.
Vallisneria americana	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Paschal *et al.*, 1982; Rybicki *et al.*, 1987; Stevenson and Confer, 1978; Aerial Survey Database 1987.
Zannichellia palustris	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Paschal *et al.*, 1982; Stevenson and Confer, 1978.
Zostera marina	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stevenson and Confer, 1978; Aerial Survey Database 1978; Orth and Nowak, 1990.

Segment TF3 — Upper Rappahannock River

Species	Reference
Ceratophyllum demersum	Orth *et al.*, 1979.
Ruppia maritima	Orth, 1971; Stevenson and Confer, 1978.
Zannichellia palustris	Stevenson and Confer, 1978.
Zostera marina	Orth, 1971; Orth, 1973; Stevenson and Confer, 1978.

Segment RET3 — Middle Rappahannock River

Species	Reference
Callitriche verna	Orth *et al.*, 1979.
Ceratophyllum demersum	Orth *et al.*, 1979.
Najas sp.	Orth *et al.*, 1979.
Potamogeton epihydrus	Stevenson and Confer, 1978.
Ruppia maritima	Orth, 1971; Stevenson and Confer, 1978; Orth and Nowak, 1990.
Vallisneria americana	Orth *et al.*, 1979.
Zannichellia palustris	Stevenson and Confer, 1978; Orth *et al.*, 1979.
Zostera marina	Orth, 1971; Orth, 1973; Stevenson and Confer, 1978; Orth and Nowak, 1990.

Segment LE3 — Lower Rappahannock River

Species	Reference
Ceratophyllum demersum	Orth *et al.*, 1979.
Callitriche verna	Orth *et al.*, 1979.
Elodea canadensis	Orth *et al.*, 1979.
Najas sp.	Orth *et al.*, 1979.
Nitella flexilis	Orth *et al.*, 1979.
Myriophyllum spicatum	Orth *et al.*, 1979.
Potamogeton epihydrus	Stevenson and Confer, 1978.
Ruppia maritima	Orth, 1971; Orth, 1973; Stevenson and Confer, 1978; Aerial Survey Database 1987; Orth *et al.*, 1979; Orth and Nowak, 1990.
Zannichellia palustris	Stevenson and Confer, 1978; Orth *et al.*, 1979.
Zostera marina	Orth, 1973; Stevenson and Confer, 1978; Aerial Survey Database 1987; Orth *et al.*, 1979; Orth and Nowak, 1990.

Segment TF4 — Upper York River

Species	Reference
Ceratophyllum demersum	Orth *et al.*, 1979.
Elodea canadensis	Stevenson and Confer, 1978.
Nitella flexilis	Orth *et al.*, 1979.
Potamogeton pectinatus	Stevenson and Confer, 1978.
Ruppia maritima	Orth, 1971; Orth, 1973; Stevenson and Confer, 1978.
Vallisneria americana	Stevenson and Confer, 1978; Orth *et al.*, 1979.
Zannichellia palustris	Orth *et al.*, 1979.
Zostera marina	Stevenson and Confer, 1978.

Segment RET4 — Middle York River

Species	Reference
Elodea canadensis	Stevenson and Confer, 1978.
Potamogeton pectinatus	Stevenson and Confer, 1978.
Ruppia maritima	Orth, 1971; Orth, 1973; Stevenson and Confer, 1978; Orth and Nowak, 1990.
Vallisneria americana	Stevenson and Confer, 1978.
Zostera marina	Stevenson and Confer, 1978; Orth and Nowak, 1990.

Segment LE4 — Lower York River

Species	Reference
Elodea canadensis	Stevenson and Confer, 1978.
Potamogeton pectinatus	Stevenson and Confer, 1978.
Ruppia maritima	Orth, 1971; Orth, 1973; Stevenson and Confer, 1978; Aerial Survey Database 1987; Orth and Nowak, 1990.
Vallisneria americana	Stevenson and Confer, 1978.
Zostera marina	Orth, 1971; Orth, 1973; Stevenson and Confer, 1978; Aerial Survey Database 1987; Orth and Nowak, 1990.

Segment WE4 — Mobjack Bay

Species	**Reference**
Elodea canadensis	Stevenson and Confer, 1978.
Potamogeton pectinatus	Stevenson and Confer, 1978.
Ruppia maritima	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Orth, 1971; Orth, 1973; Stevenson and Confer, 1978; Aerial Survey Database 1987; Orth *et al.*, 1979; Orth and Nowak, 1990.
Vallisneria americana	Stevenson and Confer, 1978.
Zostera marina	Orth, 1971; Orth, 1973; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stevenson and Confer, 1978; Aerial Survey Database 1987; Orth *et al.*, 1979; Orth and Nowak, 1990.

Segment TF5 — Upper James River

Species	**Reference**
Ceratophyllum demersum	Orth and Nowak, 1990.
Chara sp.	Orth and Nowak, 1990.
Najas guadalupensis	Orth and Nowak, 1990.

Segment RET5 —Middle James River

Species	**Reference**
Ceratophyllum demersum	Orth *et al.*, 1979.
Chara sp.	Orth and Nowak, 1990.
Najas sp.	Orth *et al.*, 1979.
Najas guadalupensis	Orth and Nowak, 1990.
Ruppia maritima	Aerial Survey Database 1987.
Zostera marina	Aerial Survey Database 1987.

Segment LE5 — Lower James River

Species	**Reference**
Ceratophyllum demersum	Orth *et al.*, 1979.

Segment LE5 — Lower James River (Continued)

Species	Reference
Najas sp.	Orth *et al.*, 1979.
Ruppia maritima	Aerial Survey Database 1987.
Zostera marina	Aerial Survey Database 1987; Orth and Nowak, 1990.

Segment ET1 — Northeast River

Species	Reference
Ceratophyllum demersum	Stevenson and Confer, 1978; Orth and Nowak, 1990.
Chara sp.	Stotts, 1970; Stevenson and Confer, 1978.
Elodea canadensis	Stevenson and Confer, 1978.
Hydrilla verticillata	Orth and Nowak, 1990.
Myriophyllum spicatum	Stotts, 1970; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Aerial Survey Database 1987; Orth and Nowak, 1990.
Najas sp.	Stevenson and Confer, 1978.
Potamogeton crispus	Orth and Nowak, 1990.
Potamogeton pectinatus	Orth and Nowak, 1990.
Potamogeton perfoliatus	Stevenson and Confer, 1978.
Vallisneria americana	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1970; Stevenson and Confer, 1978; Aerial Survey Database 1987; Orth and Nowak, 1990.
Zannichellia palustris	Stevenson and Confer, 1978; Orth and Nowak, 1990.

Segment ET2 — Elk and Bohemia Rivers

Species	Reference
Ceratophyllum demersum	Stevenson and Confer, 1978; Orth and Nowak, 1990.
Chara sp.	Stotts, 1970; Stevenson and Confer, 1978.
Elodea canadensis	Brush and Hilgartner, 1989; Stevenson and Confer, 1978; Orth and Nowak, 1990.

Segment ET2 — Elk and Bohemia Rivers (Continued)

Species	Reference
Heteranthera dubia	Aerial Survey Database 1987.
Hydrilla verticillata	Aerial Survey Database 1987; Orth and Nowak, 1990.
Myriophyllum spicatum	Stotts, 1970; Stevenson and Confer, 1978; Aerial Survey Database 1987; Orth and Nowak, 1990.
Najas sp.	Stevenson and Confer, 1978; Aerial Survey Database 1987.
Najas guadalupensis	Brush and Hilgartner, 1989.
Najas gracillima	Brush and Hilgartner, 1989.
Potamogeton crispus	Orth and Nowak, 1990.
Potamogeton diversifolius	Brush and Hilgartner, 1989.
Potamogeton pectinatus	Aerial Survey Database 1987; Orth and Nowak, 1990.
Potamogeton perfoliatus	Brush and Hilgartner, 1989; Stevenson and Confer, 1978.
Ruppia maritima	Orth and Nowak, 1990.
Vallisneria americana	Brush and Hilgartner, 1989; Stotts, 1970; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Aerial Survey Database 1987; Orth and Nowak, 1990.
Zannichellia palustris	Brush and Hilgartner, 1989; Stevenson and Confer, 1978; Orth and Nowak, 1990.

Segment ET3 — Sassafras River

Species	Reference
Chara sp.	Stevenson and Confer, 1978.
Ceratophyllum demersum	Elser, 1969; Stevenson and Confer, 1978; Aerial Survey Database 1987; Orth and Nowak, 1990.
Elodea canadensis	Brush and Hilgartner, 1989; Stevenson and Confer, 1978; Aerial Survey Database 1987; Orth and Nowak, 1990.
Heteranthera dubia	Aerial Survey Database 1987.
Hydrilla verticillata	Aerial Survey Database 1987; Orth and Nowak, 1990.

Segment ET3 — Sassafras River (Continued)

Species	Reference
Myriophyllum spicatum	Elser, 1969; Stotts, 1970; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Aerial Survey Database 1987; Orth and Nowak, 1990.
Najas sp.	Elser, 1969; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1970; Stevenson and Confer, 1978; Aerial Survey Database 1987.
Najas gracillima/muenscheri	Brush and Hilgartner, 1989.
Najas guadalupensis	Brush and Hilgartner, 1989.
Potamogeton crispus	Orth *et al.*, 1987; Orth and Nowak, 1990.
Potamogeton pectinatus	Aerial Survey Database 1987; Orth and Nowak, 1990.
Potamogeton perfoliatus	Brush and Hilgartner, 1989; Stevenson and Confer, 1978.
Ruppia maritima	Orth and Nowak, 1990.
Trapa natans	Aerial Survey Database 1987.
Vallisneria americana	Elser, 1969; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1970; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Aerial Survey Database 1987; Orth and Nowak, 1990.
Zannichellia palustris	Brush and Hilgartner, 1989; Orth and Nowak, 1990.

Segment ET4 —Chester River

Species	Reference
Ceratophyllum demersum	Stotts, 1960; Stevenson and Confer, 1978.
Chara sp.	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1970; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986.
Elodea canadensis	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1960; Stotts, 1970; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Orth and Nowak, 1990.

Segment ET4 —Chester River (Continued)

Species	Reference
Myriophyllum spicatum	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1960; Stotts, 1970; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Orth and Nowak, 1990.
Najas sp.	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1960; Stotts, 1970; Stevenson and Confer, 1978.
Najas guadalupensis	Brush and Hilgartner, 1989; Maryland Department of Natural Resources Ground Survey, 1971-1986.
Najas gracillima	Brush and Hilgartner, 1989.
Potamogeton pectinatus	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1960; Stotts, 1970; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Aerial Survey Database 1987; Orth and Nowak, 1990.
Potamogeton perfoliatus	Brush and Hilgartner, 1989; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1960; Stotts, 1970; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Aerial Survey Database 1987; Orth and Nowak, 1990.
Potamogeton pusillus	Maryland Department of Natural Resources Ground Survey, 1971-1986.
Ruppia maritima	Brush and Hilgartner, 1989; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1960; Stotts, 1970; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Aerial Survey Database 1987; Orth and Nowak, 1990.
Vallisneria americana	Brush and Hilgartner, 1989; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1970; Stevenson and Confer, 1978.
Zannichellia palustris	Brush and Hilgartner, 1989; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1970; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Orth and Nowak, 1990.
Zostera marina	Stotts, 1970; Stevenson and Confer, 1978.

Segment ET5 — Choptank River

Species	Reference
Elodea canadensis	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stewart, 1962; Stotts, 1960; Stotts, 1970; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986.

Segment ET5 — Choptank River (Continued)

Species	Reference
Myriophyllum spicatum	Stotts, 1970; Stevenson and Confer, 1978.
Najas guadalupensis	Maryland Department of Natural Resources Ground Survey, 1971-1986.
Potamogeton pectinatus	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stewart, 1962; Stotts, 1970; Stevenson and Confer, 1978; Aerial Survey Database 1987; Orth and Nowak, 1990.
Potamogeton perfoliatus	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1960; Stotts, 1970; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986.
Ruppia maritima	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stewart, 1962; Stotts, 1960; Stotts, 1970; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Aerial Survey Database 1987; Orth and Nowak, 1990.
Vallisneria americana	Stotts, 1970; Stevenson and Confer, 1978.
Zannichellia palustris	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1970; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Aerial Survey Database 1987; Orth and Nowak, 1990.
Zostera marina	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stewart, 1962; Stotts, 1960; Stotts, 1970; Stevenson and Confer, 1978.

Segment ET6 — Nanticoke River

Species	Reference
Myriophyllum spicatum	Stevenson and Confer, 1978.
Potamogeton pectinatus	Stevenson and Confer, 1978.
Potamogeton perfoliatus	Stevenson and Confer, 1978.
Ruppia maritima	Stotts, 1970; Stevenson and Confer, 1978; Orth and Nowak, 1990.

Segment ET7 — Wicomico River

Species	Reference
Myriophyllum spicatum	Stevenson and Confer, 1978.
Potamogeton pectinatus	Stevenson and Confer, 1978.

Segment ET7 — Wicomico River (Continued)

Species	Reference
Potamogeton perfoliatus	Stevenson and Confer, 1978.
Ruppia maritima	Stotts, 1970; Stevenson and Confer, 1978; Aerial Survey Database 1987; Orth and Nowak, 1990.

Segment ET8 — Manokin River

Species	Reference
Elodea canadensis	Maryland Department of Natural Resources Ground Survey, 1971-1986.
Potamogeton pectinatus	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1970; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986.
Ruppia maritima	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Aerial Survey Database 1987; Orth and Nowak, 1990.
Zannichellia palustris	Maryland Department of Natural Resources Ground Survey, 1971-1986.
Zostera marina	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1970; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Aerial Survey Database 1987.

Segment ET9 — Big Annemessex River

Species	Reference
Potamogeton pectinatus	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986.
Potamogeton perfoliatus	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stevenson and Confer, 1978.
Ruppia maritima	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Aerial Survey Database 1987; Orth and Nowak, 1990.
Zostera marina	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Aerial Survey Database 1987.

Segment ET10 — Pocomoke River

Species	Reference
Ruppia maritima	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1970; Stevenson and Confer, 1978; Orth and Nowak, 1990.
Zostera marina	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1970; Stevenson and Confer, 1978.

Segment EE1 — Eastern Bay

Species	Reference
Chara sp.	Stotts, 1970; Stevenson and Confer 1978.
Ceratophyllum demersum	Fenwick, unpublished; Stevenson and Confer, 1978.
Elodea canadensis	Fenwick, unpublished; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1960; Stotts, 1970; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986.
Myriophyllum spicatum	Elser, 1969; Fenwick, unpublished; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1970; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986.
Najas sp.	Fenwick, unpublished; Stevenson and Confer, 1978.
Najas guadalupensis	Brush and Hilgartner, 1989.
Potamogeton pectinatus	Fenwick, unpublished; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1960; Stotts, 1970; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Orth and Nowak, 1990.
Potamogeton perfoliatus	Fenwick, unpublished; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1960; Stotts, 1970; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Aerial Survey Database 1987.
Ruppia maritima	Fenwick, unpublished; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1960; Stotts, 1970; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Aerial Survey Database 1987; Orth and Nowak, 1990.

Segment EE1 — Eastern Bay (Continued)

Species	Reference
Zannichellia palustris	Brush and Hilgartner, 1989; Fenwick, unpublished; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1970; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Aerial Survey Database 1987; Orth and Nowak, 1990.
Zostera marina	Fenwick, unpublished; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1960; Stotts, 1970; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986.

Segment EE2 — Lower Choptank River

Species	Reference
Elodea canadensis	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stewart, 1962; Stotts, 1960; Stotts, 1970; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986.
Myriophyllum spicatum	Stotts, 1970; Stevenson and Confer, 1978.
Potamogeton pectinatus	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stewart, 1962; Stotts, 1970; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Aerial Survey Database 1987; Orth and Nowak, 1990.
Potamogeton perfoliatus	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1960; Stotts, 1970; Stevenson and Confer, 1978; Brush and Hilgartner, 1989; Maryland Department of Natural Resources Ground Survey, 1971-1986.
Ruppia maritima	Brush, 1987; Brush and Hilgartner, 1989; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stewart, 1962; Stotts, 1960; Stotts, 1970; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Aerial Survey Database 1987; Orth and Nowak, 1990.
Vallisneria americana	Stotts, 1970; Stevenson and Confer, 1978.
Zannichellia palustris	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1970; Stevenson and Confer, 1978; Brush, 1987; Brush and Hilgartner, 1989; Maryland Department of Natural Resources Ground Survey, 1971-1986; Aerial Survey Database 1987; Orth and Nowak, 1990.

Segment EE2 — Lower Choptank River

Species	Reference
Zostera marina	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stewart, 1962; Stotts, 1960; Stotts, 1970; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Aerial Survey Database 1987.

Segment EE3 — Tangier Sound

Species	Reference
Chara sp.	Stevenson and Confer, 1978.
Myriophyllum spicatum	Stevenson and Confer, 1978.
Potamogeton pectinatus	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stewart, 1962; Stotts, 1970; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986.
Potamogeton perfoliatus	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1970; Stevenson and Confer, 1978.
Ruppia maritima	Brush and Hilgartner, 1989; Elser, 1969; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1960; Stotts, 1970; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986; Aerial Survey Database 1987; Orth and Nowak, 1990.
Zannichellia palustris	Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stevenson and Confer, 1978; Maryland Department of Natural Resources Ground Survey, 1971-1986.
Zostera marina	Elser, 1969; Kerwin *et al.*, 1975a; Kerwin *et al.*, 1975b; Munro, 1976a; Munro, 1976b; Stotts, 1960; Stotts, 1970; Maryland Department of Natural Resources Ground Survey, 1971-1986; Aerial Survey Database 1987; Orth and Nowak, 1990.

Appendix C — Table 2

Table C-2. Chesapeake Bay SAV species distribution/diversity restoration targets by CBP segment.

SEGMENT CB1
NORTHERN CHESAPEAKE BAY

Ceratophyllum demersum

Chara sp.

Elodea canadensis

Heteranthera dubia

Myriophyllum spicatum

Najas sp.

Najas flexilis

Najas gracillima

Najas guadalupensis

Najas minor

Potamogeton amplifolius

Potamogeton gramineus

Potamogeton nodosus

Potamogeton diversifolius

Potamogeton epihydrus

Potamogeton pectinatus

Potamogeton perfoliatus

Vallisneria americana

Zannichellia palustris

SEGMENT CB2
UPPER CHESAPEAKE BAY

Ceratophyllum demersum

Chara sp.

Elodea canadensis

Heteranthera dubia

Hydrilla vericillata

Myriophyllum spicatum

Najas sp.

Najas guadalupensis

Potamogeton crispus

Potamogeton pectinatus

Potamogeton perfoliatus

Ruppia maritima

Vallisneria americana

Zannichellia palustris

SEGMENT CB3
UPPER CENTRAL CHESAPEAKE BAY

Ceratophyllum demersum

Chara sp.

Elodea canadensis

Myriophyllum spicatum

Najas sp.

SEGMENT CB3
UPPER CENTRAL CHESAPEAKE BAY (CONT.)

Najas guadalupensis

Potamogeton crispus

Potamogeton pectinatus

Potamogeton perfoliatus

Ruppia maritima

Vallisneria americana

Zannichellia palustris

Zostera marina

SEGMENT CB4
MIDDLE CENTRAL CHESAPEAKE BAY

Ceratopyllum demersum

Elodea canadensis

Myriophyllum spicatum

Potamogeton pectinatus

Potamogeton perfoliatus

Ruppia maritima

Vallisneria americana

Zannichellia palustris

Zostera marina

SEGMENT CB5
LOWER CHESAPEAKE BAY

Potamogeton pectinatus

Ruppia maritima

Zannichellia palustris

Zostera marina

SEGMENT CB6
WESTERN LOWER CHESAPEAKE BAY

Ruppia maritima

Zannichellia palustris

Zostera marina

SEGMENT CB7
EASTERN LOWER CHESAPEAKE BAY

Potamogeton pectinatus

Ruppia maritima

Zannichellia palustris

Zostera marina

SEGMENT CB8
MOUTH OF CHESAPEAKE BAY

Ruppia maritima

Zannichellia palustris

Zostera marina

SEGMENT WT1
BUSH RIVER

Ceratophyllum demersum

Chara sp.

Elodea canadensis

Heteranthera dubia

Myriophyllum spicatum

Najas sp.

Najas guadalupensis

Potamogeton pectinatus

Potamogeton perfoliatus

Ruppia maritima

Vallisneria americana

Zannichellia palustris

SEGMENT WT2 GUNPOWDER RIVER

Ceratophyllum demersum

Chara sp.

Elodea canadensis

Heteranthera dubia

Myriophyllum spicatum

Najas sp.

Najas guadalupensis

Najas gracillima

Potamogeton pectinatus

Potamogeton perfoliatus

Ruppia maritima

Vallisneria americana

Zannichellia palustris

SEGMENT WT3 MIDDLE RIVER

Ceratophyllum demersum

Chara sp.

Elodea canadensis

Heteranthera dubia

Myriophyllum spicatum

Najas sp.

Najas guadalupensis

Najas gracillimas

Potamogeton crispus

Potamogeton pectinatus

Potamogeton perfoliatus

Ruppia maritima

Vallisneria americana

Zannichellia palustris

SEGMENT WT4 BACK RIVER

Ceratophyllum demersum

Chara sp.

Elodea canadensis

Heteranthera dubia

Myriophyllum spicatum

Najas sp.

Najas guadalupensis

Najas gracillima

Potamogeton pectinatus

Potamogeton perfoliatus

Ruppia maritima

Vallisneria americana

Zannichellia palustris

SEGMENT WT5 PATAPSCO RIVER

Ceratophyllum demersum

Chara sp.

Elodea canadensis

Myriophyllum spicatum

Najas sp.

Najas guadalupensis

SEGMENT WT5
PATAPSCO RIVER (CONT.)

Potamogeton pectinatus

Potamogeton perfoliatus

Ruppia maritima

Vallisneria americana

Zannichellia palustris

SEGMENT WT6
MAGOTHY RIVER

Ceratophyllum demersum

Chara sp.

Elodea canadensis

Heteranthera dubia

Myriophyllum spicatum

Najas sp.

Najas guadalupensis

Potamogeton pectinatus

Potamogeton perfoliatus

Ruppia maritima

Vallisneria americana

Zannichellia palustris

SEGMENT WT7
SEVERN RIVER

Ceratophyllum demersum

Chara sp.

Elodea canadensis

Myriophyllum spicatum

Najas sp.

Najas guadalupensis

Potamogeton pectinatus

Potamogeton perfoliatus

Ruppia maritima

Vallisneria americana

Zannichellia palustris

SEGMENT WT8
SOUTH, RHODE, AND WEST RIVERS

Elodea canadensis

Myriophyllum spicatum

Potamogeton pectinatus

Potamogeton perfoliatus

Ruppia maritima

Vallisneria americana

Zannichellia palustris

SEGMENT TF1
UPPER PATUXENT RIVER

Chara sp.

Ceratopyllum demersum

Elodea canadensis

Heteranthera dubia

Myriophyllum spicatum

Najas sp.

Najas flexilis

Najas guadalupensis

Potamogeton crispus

Potamogeton diversifolius

Potamogeton epihydrus

Potamogeton pectinatus

Potamogeton perfoliatus

Potamogeton pusillus

Ruppia maritima

Vallisneria americana

Zannichellia palustris

Zostera marina

SEGMENT RET1
MIDDLE PATUXENT RIVER

Ceratophyllum demersum

Chara sp.

Elodea canadensis

Myriophyllum spicatum

Najas sp.

Najas flexilis

Najas guadalupensis

Potamogeton crispus

Potamogeton diversifolius

Potamogeton epihydrus

Potamogeton pectinatus

Potamogeton perfoliatus

Potamogeton pusillus

Ruppia maritima

Vallisneria americana

Zannichellia palustris

Zostera marina

SEGMENT LE1
LOWER PATUXENT RIVER

Elodea canadensis

Myriophyllum spicatum

Najas sp.

Ptamogeton pectinatus

Potamogeton perfoliatus

Ruppia maritima

Vallisneria americana

Zannichellia palustris

Zostera marina

SEGMENT TF2
UPPER POTOMAC RIVER

Ceratophyllum demersum

Chara sp.

Egeria densa

Elodea canadensis

Heteranthera dubia

Myriophyllum spicatum

Najas sp.

Najas minor

Najas guadalupensis

Najas gracillima

Nitella flexilis

Potamogeton crispus

Potamogeton pectinatus

Potamogeton perfoliatus

Potamogeton pusillus

Ruppia maritima

SEGMENT TF2
UPPER POTOMAC RIVER (CONT.)

Vallisneria americana

Zannichellia palustris

SEGMENT RET2
MIDDLE POTOMAC RIVER

Ceratophyllum demersum

Chara sp.

Elodea canadensis

Heteranthera dubia

Myriophyllum spicatum

Najas sp.

Najas guadalupensis

Najas minor

Potamogeton crispus

Potamogeton pectinatus

Potamogeton perfoliatus

Potamogeton pusillus

Ruppia maritima

Vallisneria americana

Zannichellia palustris

SEGMENT LE2
LOWER POTOMAC RIVER

Chara sp.

Elodea canadensis

Myriophyllum spicatum

Najas sp.

Najas guadalupensis

Potamogeton crispus

Potamogeton pectinatus

Potamogeton perfoliatus

Potamogeton pusillus

Ruppia maritima

Vallisneria americana

Zannichellia palustris

Zostera marina

SEGMENT TF3
UPPER RAPPAHANNOCK RIVER

Ceratophyllum demersum

Chara sp.

Elodea canadensis

Heteranthera dubia

Myriophyllum spicatum

Najas guadalupensis

Potamogeton pectinatus

Potamogeton perfoliatus

Ruppia maritima

Vallisneria americana

Zannichellia palustris

Zostera marina

SEGMENT RET3
MIDDLE RAPPAHANNOCK RIVER

Callitriche verna

Ceratophyllum demersum

Elodea canadensis

Heteranthera dubia

Myriophyllum spicatum

Najas sp.

Potamogeton

Potamogeton pectinatus

Potamogeton perfoliatus

Ruppia maritima

Vallisneria americana

Zannichellia palustris

Zostera marina

SEGMENT LE3
LOWER RAPPAHANNOCK RIVER

Ceratophyllum demersum

Callitriche verna

Elodea canadensis

Najas sp.

Nitella flexilis

Myriophyllum spicatum

Potamogeton

Ruppia maritima

Zannichellia palustris

Zostera marina

SEGMENT TF4
UPPER YORK RIVER

Chara sp.

Ceratophyllum demersum

Elodea canadensis

Heteranthera dubia

Myriophyllum spicatum

Najas guadalupensis

Nitella flexilis

Potamogeton pectinatus

Potamogeton perfoliatus

Ruppia maritima

Vallisneria americana

Zannichellia palustris

Zostera marina

SEGMENT RET4
MIDDLE YORK RIVER

Elodea canadensis

Myriophyllum spicatum

Najas guadalupensis

Potamogeton perfoliatus

Potamogeton pectinatus

Ruppia maritima

Vallisneria americana

Zannichellia palustris

Zostera marina

SEGMENT LE4
LOWER YORK RIVER

Elodea canadensis

Potamogeton pectinatus

Ruppia maritima

Vallisneria americana

Zannichellia palustris

Zostera marina

SEGMENT WE4
MOBJACK BAY

Elodea canadensis

Potamogeton pectinatus

Ruppia maritima

Vallisneria americana

Zannichellia palustris

Zostera marina

SEGMENT TF5
UPPER JAMES RIVER

Ceratophyllum demersum

Chara sp.

Elodea canadensis

Heteranthera dubia

Myriophyllum spicatum

Najas guadalupensis

Potamogeton pectinatus

Potamogeton perfoliatus

Vallisneria americana

Zannichellia palustris

SEGMENT RET5
MIDDLE JAMES RIVER

Ceratophyllum demersum

Chara sp.

Elodea canadensis

Heteranthera dubia

Myriophyllum spicatum

Najas sp.

Najas guadalupensis

Potamogeton pectinatus

Potamogeton perfoliatus

Ruppia maritima

Vallisneria americana

Zannichellia palustris

Zostera marina

SEGMENT LE5
LOWER JAMES RIVER

Ceratophyllum demersum

Najas sp.

Ruppia maritima

Zannichellia palustris

Zostera marina

SEGMENT ET1
NORTHEAST RIVER

Ceratophyllum demersum

Chara sp.

Elodea canadensis

Heteranthera dubia

Myriophyllum spicatum

Najas sp.

Najas guadalupensis

Potamogeton crispus

Potamogeton pectinatus

Potamogeton perfoliatus

Vallisneria americana

Zannichellia palustris

SEGMENT ET2
ELK AND BOHEMIA RIVERS

Ceratophyllum demersum

Chara sp.

Elodea canadensis

Heteranthera dubia

Myriophyllum spicatum

Najas sp.

Najas guadalupensis

Najas gracillima

Potamogeton crispus

Potamogeton diversifolius

Potamogeton pectinatus

Potamogeton perfoliatus

Ruppia maritima

Vallisneria americana

Zannichellia palustris

SEGMENT ET3
SASSAFRAS RIVER

Chara sp.

Ceratophyllum demersum

Elodea canadensis

Heteranthera dubia

Myriophyllum spicatum

Najas sp.

Najas gracillima/muenscheri

Najas guadalupensis

Potamogeton crispus

Potamogeton pectinatus

Potamogeton perfoliatus

Ruppia maritima

Trapa natans

Vallisneria americana

Zannichellia palustris

SEGMENT ET4
CHESTER RIVER

Ceratophyllum demersum

Chara sp.

Elodea canadensis

Heteranthera dubia

Myriophyllum spicatum

Najas sp.

Najas guadalupensis

Najas gracillima

Potamogeton pectinatus

Potamogeton perfoliatus

Potamogeton pusillus

Ruppia maritima

Vallisneria americana

Zannichellia palustris

Zostera marina

SEGMENT ET5
CHOPTANK RIVER

Ceratophyllum demersum

Chara sp.

Elodea canadensis

Heteranthera dubia

SEGMENT ET5
CHOPTANK RIVER (CONT.)

Myriophyllum spicatum

Najas guadalupensis

Potamogeton pectinatus

Potamogeton perfoliatus

Ruppia maritima

Vallisneria americana

Zannichellia palustris

Zostera marina

SEGMENT ET6
NANTICOKE RIVER

Elodea canadensis

Myriophyllum spicatum

Potamogeton pectinatus

Potamogeton perfoliatus

Ruppia maritima

Zannichellia palustris

Zostera marina

SEGMENT ET7
WICOMICO RIVER

Myriophyllum spicatum

Potamogeton pectinatus

Potamogeton perfoliatus

Ruppia maritima

Zannichellia palustris

Zostera marina

SEGMENT ET8
MANOKIN RIVER

Elodea canadensis

Potamogeton pectinatus

Ruppia maritima

Zannichellia palustris

Zostera marina

SEGMENT ET9
BIG ANNEMESSEX RIVER

Potamogeton pectinatus

Potamogeton perfoliatus

Ruppia maritima

Zannichellia palustris

Zostera marina

SEGMENT ET10
POCOMOKE RIVER

Ruppia maritima

Zannichellia palustris

Zostera marina

SEGMENT EE1
EASTERN BAY

Chara sp.

Ceratophyllum demersum

Elodea canadensis

Myriophyllum spicatum

Najas sp.

Najas guadalupensis

Potamogeton pectinatus

Potamogeton perfoliatus

Ruppia maritima

Zannichellia palustris

Zostera marina

SEGMENT EE2
LOWER CHOPTANK RIVER

Elodea canadensis

Myriophyllum spicatum

Potamogeton pectinatus

Potamogeton perfoliatus

Ruppia maritima

Vallisneria americana

Zannichellia palustris

Zostera marina

SEGMENT EE3
TANGIER SOUND

Chara sp.

Myriophyllum spicatum

Potamogeton pectinatus

Potamogeton perfoliatus

Ruppia maritima

Zannichellia palustris

Zostera marina

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